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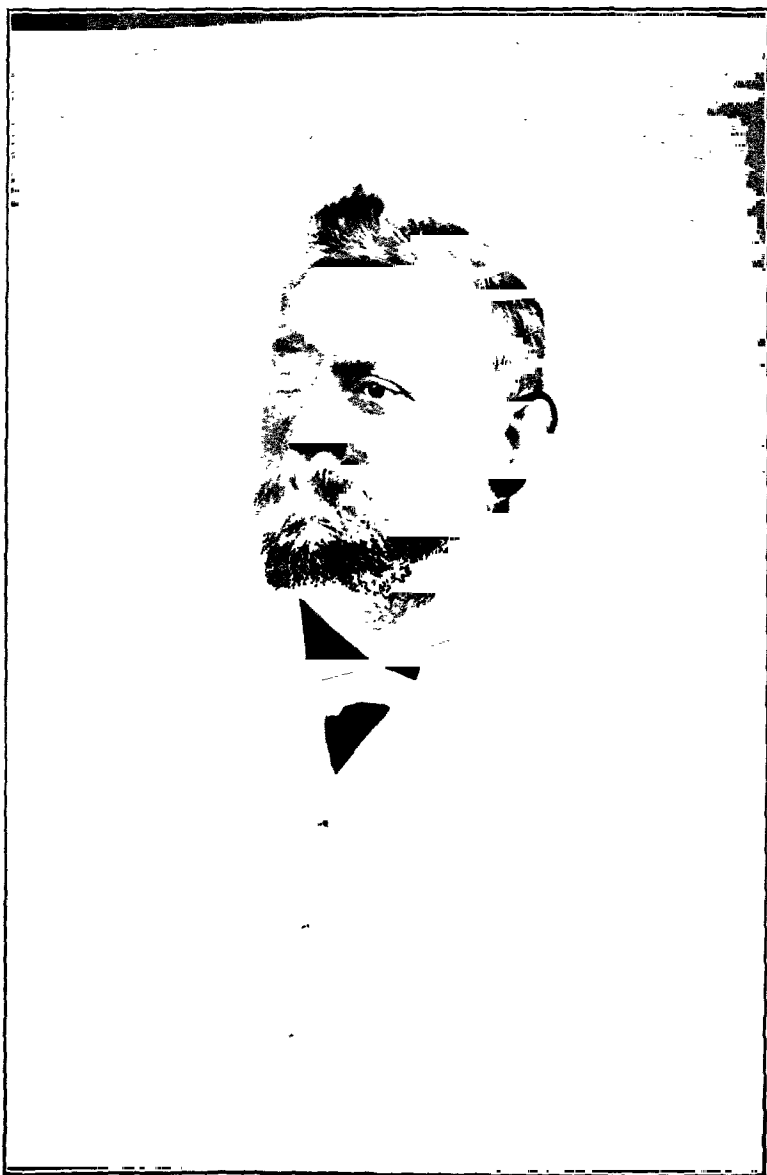


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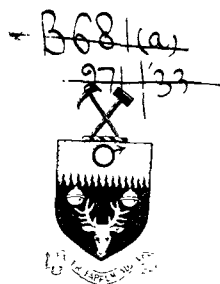
OF THE

IRON AND STEEL INSTITUTE

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EDITED BY
GEORGE C. LLOYD
SECRETARY



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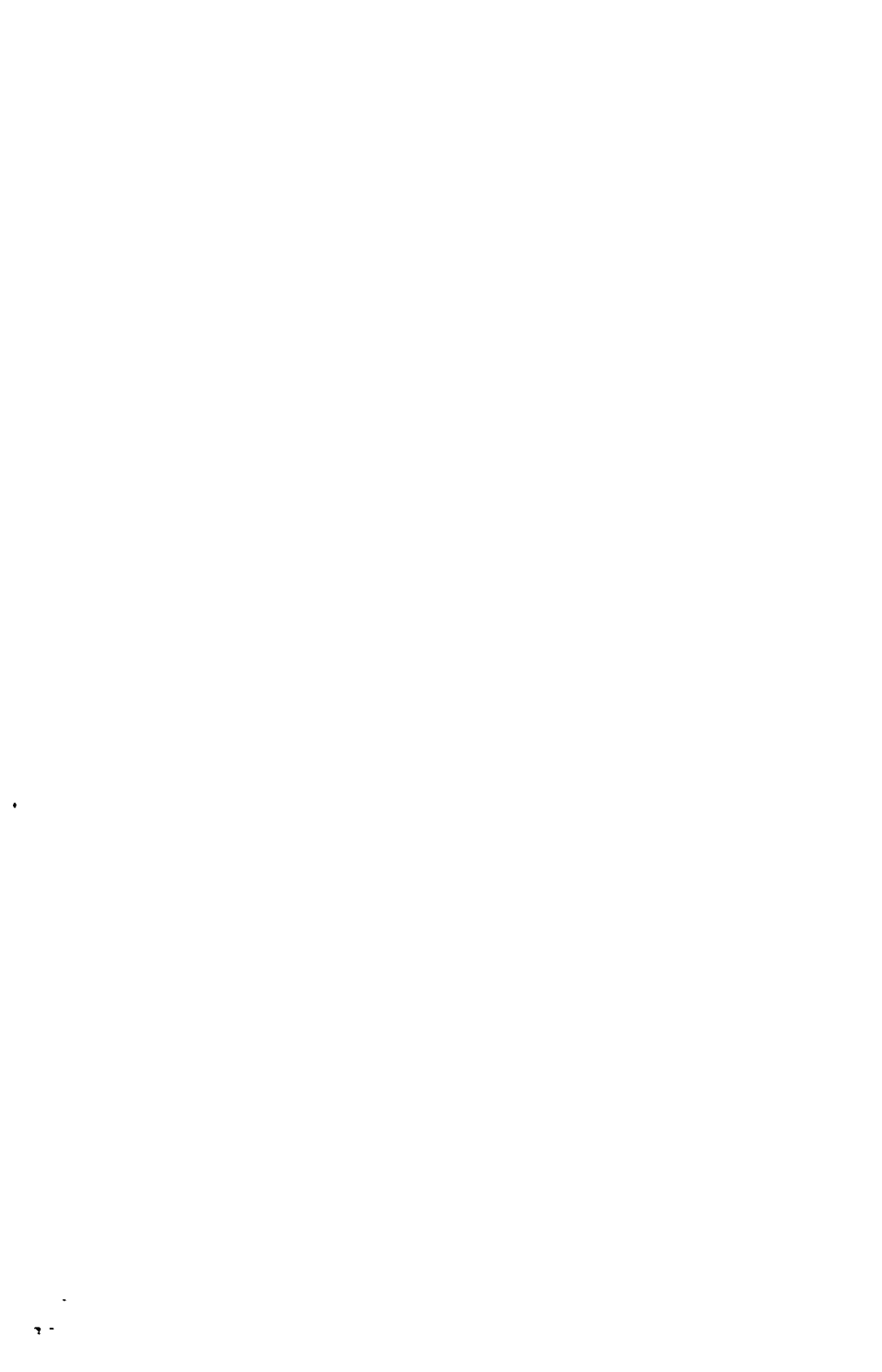
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PREFACE.

THIS volume contains the proceedings of the Annual General Meeting of the Iron and Steel Institute, held in London on May 1912, together with the papers presented for reading and discussion at the meeting. The remainder of the volume consists, as usual, of Obituary Notices relating to deceased members, the Library Reports, and Notes on the Progress of the Home and Foreign Industries during the first half of 1912, with a Bibliography of works on Mining and Metallurgy published during that period. 


 28 VICTORIA STREET, LONDON,
July 31, 1912.  



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THE IRON AND STEEL INSTITUTE.

SECTION I. *MINUTES OF PROCEEDINGS.*

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, May 9 and 10, 1912—His Grace the DUKE OF DEVONSHIRE, President, in the chair.

The Minutes of the previous Meeting, held at the Institution of Civil Engineers on October 5, 1911, were taken as read and signed by the President as a correct record.

Mr. P. B. BROWN (Eltham), Mr. S. S. SOMERS (Halesowen), and Mr. W. A. WALBER (London) were appointed scrutineers of the ballot for the election of Members of Council, and on the completion of their scrutiny they reported that no other candidates for election as Vice-Presidents having been nominated. Mr. WILLIAM EVANS, Mr. J. E. STEAD, F.R.S., and Mr. GEORGE AINSWORTH, the retiring Vice-Presidents, had been duly re-elected. They further reported that the result of the election to fill the five vacancies on the Council due to the retirement of members in rotation was as follows:—

	Votes.
WILLIAM H. ELLIS	418
WILLIAM H. HEWLETT	437
CHARLES P. E. SCHNEIDER	409
JOHN H. DAREY	397
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Mr. Ellis, Mr. Hewlett, Mr. Schneider, Mr. Darby, and Mr. Bagley, the retiring members of Council, were accordingly declared duly re-elected.

Mr. WILLIAM CROSS (London) and Mr. J. ETHERINGTON (London) were appointed scrutineers of the ballot for the election of new members, and reported that the following fifty-two candidates had been duly elected:—

NAME.	ADDRESS.	PROPOSERS.
Abbott, Robert Rowell, B.Sc.	The Peerless Motor Car Company, Cleveland, Ohio, U.S.A.	H. A. Baxter, H. M. Lane, H. W. Lash
Allen, Henry Butler.	641 Washington Street, New York City, U.S.A.	W. Campbell, H. M. Howe, B. Stoughton.
Barker, James . . .	Victoria Iron Works, Todmorden, Lancashire	C. E. Siddall, E. Pearce, F. Hardwick.
Bennett, Ellis H. . .	88 Mosley Street, Manchester	J. W. Thompson, F. Hardwick, F. T. Rollin.
Birley, Samuel . . .	149 Mayor Street, Bolton, Lancashire	J. O. Arnold, A. McWilliam, E. F. Lange.
Blank, Otto	Duisburg, Germany . .	A. Cooper, P. N. Cunningham, D. Hunter.
Caplen, Tom	Chipmunkpalle P.O., Vizagapatam District, India	H. G. Turner, E. F. Law, J. Angus.
Clasen, Bernard . .	Norfolk House, Laurence Pountney Hill, London, E.C.	J. P. Bedson, J. H. Harrison, J. Rider, Jun.
Coe, Henry Ivor, M.Sc.	Municipal Technical School, Birmingham	T. Turner, O. F. Hudson, F. C. A. H. Lantberry.
Davey, Edward . . .	Messrs. John Lysaght, Ltd., St. Vincent's Iron Works, Bristol	A. Cooper, F. W. Cooper, J. E. Stead.
Davies, Stanley Richard, A.soc.R.S.M.	Tanyralit, Pontardawe, Glamorgan-shire	W. Gowland, W. D. Johnson, W. H. Merrett.
Dawkins, Crowell T.	Lake Superior Iron & Chemical Company, Ashland, Wisconsin, U.S.A.	J. Aston, J. E. Johnson, Jun., W. Wilkins.
Dickenson, Ernest Lawrence	Messrs. Sander-son Bros. & Newbould, Darnall, Sheffield	J. O. Arnold, T. W. Willis, J. H. S. Dickenson.
Drummond, Thos. J.	The Lake Superior Corporation, Montreal, Canada	Arthur Cooper, Sir Hugh Bell, Bart., G. Ainsworth.
Elliot, Thomas Gifford	Roslin Crescent, Hathersage, via Sheffield	Sir R. A. Hadfield, I. B. Milne, Ernest Ott.
Falk, Gordon Sands, B.Sc.	491 Jefferson Street, Milwaukee, Wisconsin, U.S.A.	A. Simonson, James Aston, B. Stoughton.

NAME.	ADDRESS.	PROPOSERS.
Fearneshough, William	89 Clarkehouse Road, Sheffield	Henry Stones, E. Dickinson, G. E. Senior.
Fox, Edmund John. M.I.Mech.E., M.I.E.E.	Winchester House, Old Broad Street, London E.C.	B. A. Holland, A. Lamberton, P. N. Cunningham.
Franco, Alfred . . .	103 Rue Froissart, Brussels, Belgium	Henry Louis, Fred Mills, J. O. Arnold.
Hambly, Percy Noel. Assoc.M.I.Mech.E.	The Coppée Company (Great Britain), Ltd., King's House, Kingsway, London, W.C.	W. Evans, D. E. Roberts, E. Crowe.
Hickman, W. Christie	Hawthornden, Sedgley, near Dudley	W. Hutchinson, W. Moore, A. Pool.
Hill, Cyril Francis, M.I.M.M.	308 West Ferry Road, Millwall, London, E.	A. Lamberton, J. A. Hampton, H. Silvester.
Hill, Henry George . .	Messrs. John Lysaght, Ltd., St. Vincent's Iron Works, Bristol	A. Cooper, F. W. Cooper, J. E. Stead.
Hughes, Ralph T. . .	2 Exchange Place, Middlesbrough	A. Dorman, W. Hawdon, A. B. Gridley, Francis Samuelson.
Izat, Andrew . . .	Kamptee, Central Provinces, India	H. G. Turner, E. F. Law, J. Angus.
Jenkins, Ivor O. . .	Gwylta, Peny wern, Neath	P. Longmuir, T. Swinden, I. Bagnall.
Kayser, Charles William	Endcliffe Grange, Sheffield	B. W. Winder, J. O. Arnold, G. E. Senior.
Kenrick, John Painter, Assoc.M. Inst.C.E., M.I.M.E.	Pekin Syndicate, Ltd., Honan, China	H. P. King, J. R. Hoyle, F. Best.
Kiefer, Herman Guy	The Timken Roller Bearing Co., Canton, Ohio, U.S.A.	E. D. Campbell, J. A. Mathews, M. T. Lothrop.
Kitson, Henry Herbert	Monk Bridge Ironworks, Leeds	Sir Hugh Bell, Bart., M. Mannaberg, H. W. Williams.
Lester, Walter . . .	87 Sumner Street, Southwark, London, S.E.	Wilson Cross, S. Whitmore, W. R. Lewis.
Mainprice, Max Reynier	Messrs. Brown Bayley's Steel Works, Ltd., Sheffield	R. Armitage, W. J. Armitage, W. R. Ellison.
Mitchell, George William	2 Highfield Terrace, Doncaster	C. E. Siddall, E. Pearce, J. W. Thompson.
Moon, George C. . .	217 North Avenue (East), Cranford, New Jersey, U.S.A.	W. Campbell, H. M. Howe, B. Stoughton.
Nordenfelt, Captain Åke Hjalmar	Hoganas, Sweden . . .	T. Nordenfelt, G. G. S. Grundy, C. Svedberg.
Olsson, Ivar. . . .	Falun, Sweden . . .	E. J. I. . . . A. G. . . .
Ortmann, Rudolph . .	McCormick Building, Chicago, Illinois, U.S.A.	R. W. . . . A. W. . . . F. A. Warlow.
Parker, James Heber	The Carpenter Steel Company, Reading, Pa., U.S.A.	G. W. Sargent, S. Badlam, J. A. Mathews.

NAME.	ADDRESS.	PROPOSERS.
Paton, James, B.Sc. .	6 Munro Road, Jordanhill, Glasgow	E. J. Duff, J. R. Ross, T. H. Lauder.
Pettigrew, John, F.I.C.	7 Victoria Street, Westminster, London, S.W.	W. F. Pettigrew, S. J. Robinson, J. F. Melling.
Pletsch, Louis . . .	Société Russe de Fabrication de Tubes, Nijni-Dnieprovsk, Ekaterinoslav, Russia	A. C. Lyon, G. Hatton, G. Lewis.
Puppe, Johan, Dr. Ing.	Königl. Technische Hochschule, Breslau, Germany	E. Schrödter, F. Springorum, G. Gillhausen.
Robertson, Walter Henry Antonio, Assoc. M.I. Mech. E.	Lynton Works, Bedford	P. W. Lee, A. S. Lee, J. H. Dewhurst.
Rosenbusch, Gilbert, Assoc. M.Inst. C. E.	Queen Anne's Chambers, Westminster, London, S.W.	William Evans, John Evans, David Lewis.
Scott, Harry Charles David	Arrandale, Croft's Bank Road, Urmston, near Manchester	J. W. Thompson, F. Hardwick, F. T. Rollin.
Smart, Bertram James, B.Sc.	Government Testing Office, Lithgow, N.S.W., Australia	H. Moore, G. Melland, F. Rogers.
Smith, James Cruickshank, B.Sc., F.C.S.	King's House, King Street, London, E.C.	F. W. Harbord, Sir R. A. Hadfield, G. Ainsworth.
Snyder, Robert J. .	43 East Putnam Avenue, Greenwich, Connecticut, U.S.A.	J. A. Mathews, M. T. Lothrop, J. H. Nead.
Theisen, Hans Eduard	34 Elisabethstrasse, Munich, Bavaria.	R. D. Wood, T. Westgarth, A. Greiner.
Tiemann, Hugh Philip, B.Sc., A.M.	Carnegie Steel Company, Pittsburg, Pa., U.S.A.	J. S. Unger, H. M. Howe, B. Stoughton.
Turton, Frank . .	31 Collegiate Crescent, Sheffield	S. E. Skelton, M. Wardlow, R. G. Woodward.
Williams, Frederick George	Steel Works Manager, Gun & Shell Factory, Cos-ipore, India	B. W. Winder, J. K. Jonas, L. Duffy.

The following Report of the Council upon the proceedings of the Institute during the year 1911 was read in abstract by the Secretary:—

REPORT OF COUNCIL.

At this, the forty-third Annual General Meeting of the Iron and Steel Institute, the Council have the pleasure of submitting to the members their Annual Report, and are glad to note that during the year 1911 the progress of the Institute has continued to be satisfactory.

CORONATION OF THEIR MAJESTIES KING GEORGE V.
AND QUEEN MARY.

The King, who for many years had, as Prince of Wales, honoured the Iron and Steel Institute with his support in the capacity of Honorary Member, and on his accession to the Throne became Patron of the Institute, was graciously pleased to receive and to express thanks for an illuminated address of congratulation on the occasion of their Majesties' Coronation.

ROLL OF THE INSTITUTE.

During the year 1911, 102 new members were elected, and the total membership of the Institute on December 31, 1911, was:—

Patron	1
Honorary Members	7
Life Members	60
Ordinary Members	2065
Total	<u>2133</u>

The growth of the Institute during the past forty years is shown by the following table:—

	1871.	1881.	1891.	1901.	1911.
Patron . . . . .	...			1	1
Honorary Members		7	5	9	7
Life Members				18	60
Ordinary Members	512	1188	1535	1620	2065
Totals	512	1195	1540	1648	2133

The Council desire to offer their congratulations to a number of members who have had high distinctions conferred upon them. Sir William T. Lewis, Bart., K.C.V.O., Vice-President, has been created a Peer of the United Kingdom, and has assumed the title of Lord Merthyr of Senghennydd. Mr. A. B. Markham, M.P., has been created a Baronet. The Grand Cross of the Victorian Order has been bestowed on His Excellency Admiral Arvid Lindman. Professor J. A. Ewing, F.R.S., and Mr. H. F. Donaldson, C.B., have been created Knights Commanders of the Bath, and the honour of Knighthood has been conferred upon Colonel C. J. Stoddart. Colonel H. Hughes has been made a Companion of the Order of the Bath, and has also been appointed Technical Adviser to the British Delegates to the International Industrial Property Convention at Washington, U.S.A. Mr. T. F. Butler has received from the Emperor of Japan the Third Class of the Imperial Order of the Sacred Treasure. The honorary degree of Doctor of Metallurgy has been bestowed by the University of Sheffield upon Sir Robert Hadfield, F.R.S., Past-President, and that of Master of Metallurgy on Mr. B. W. Winder. Sir Robert Hadfield has also been elected a Foreign Member of the Royal Swedish Academy of Science, Stockholm. Mr. A. Balfour has been elected Master of the Cutlers' Company of Sheffield. Sir G. B. Hingley, Bart., has been appointed Deputy-Lieutenant of the County of Worcester. Sir Hugh Bell, Bart., Sir Robert Hadfield, F.R.S., Mr. G. Ainsworth, Mr. G. H. Claughton, Mr. F. W. Gibbins, and Mr. Alexander Siemens have been appointed representatives of employers on the new Industrial Council of the Board of Trade. Colonel Leandro Cubillo of Trubia, Spain, has been promoted to General in Command of the Seventh District of Artillery at Valladolid. Professor A. McWilliam, A.R.S.M., D.Met., has been appointed Metallurgical and Analytical Inspector of Steel in India. Professor W. A. Bone, D.Sc., Ph.D., F.R.S., has been appointed Professor of the newly instituted Chair of Fuel and Refractory Materials at the Imperial College of Science and Technology. Mr. Isaac Lester has been elected President of the Staffordshire Iron and Steel Institute, Mr. Walter Dixon has been elected President of the West of Scotland Iron and Steel Institute, Professor J. O. Arnold, D.Met., has been re-elected President of the Sheffield Electro-Metallurgical Society, and Mr. Percy Longmuir has been re-elected President of the British Foundrymen's Association.

During the year 1911 the Institute has sustained heavy losses

through the death of several well-known members, including Lord Airedale, Past-President; Baron Fernand d'Huart, Honorary Vice-President; General Salvador Ordoñez; and Mr. T. Hurry Riches, Past-President of the Institution of Mechanical Engineers, besides others who have rendered valuable service to the Institute. The list comprises the following thirty-two names:—

Lord Airedale of Gledhow, Past-President	March 16.
Baron Fernand d'Huart, Hon. Vice-President	September 13.
Sir John Aird, Bart.	January 6.
Barber, John Henry (Sheffield)	October 2.
Braby, Fred. (Teddington)	October 9.
Bright, William (Gowerton)	August 14.
Brooks, J. C. (Philadelphia)	July 18.
Crossley, Sir William J., Bart. (Manchester)	October 12.
Davey, George H. (Baglan, Glam.)	September 8.
Dering, George Edward (Welwyn)	January 8.
Fullerton, Alexander (Paisley)	May 30.
Gray, Leason (Wakefield)	March 30.
Greig, Douglas W. (Modderfontein)	—
Howson, Richard (Middlesbrough)	August 2.
Jones, James (Sheffield)	March.
Kockum, Franz H. (Malmo, Sweden)	February 18.
Longbotham, Jonathan (Sheffield)	November 21.
Mair, George John (Helensburgh)	February.
Morgan, Charles H. (Worcester, U.S.A.)	January 10.
Ordoñez, General Salvador Diaz (Cartagena)	October 14.
Pope, Samuel (Pontypridd)	January 25.
Riches, Tom Hurry (Cardiff)	September 24.
Smith, C. Weston (Birmingham)	May 14.
Swan, H. A. (Middlesbrough)	December 13.
Tennent, John (Bothwell)	August 20.
Theisen, Eduard (Munich)	April 3.
Thompson, William (London)	May 27.
Thomson, John (E-ton)	August 29.
Vaughan, Cedric (Millom)	February 18.
Wake, H. H. (Sunderland)	February 17.
Webster, Cyril Grey (London)	February 19.

The death of Azariah Griffiths (Falkirk) occurred on May 19, 1910, but was not noted in the Council Report for that year.

James Kitson, Baron Airedale of Gledhow, who at the time of his death was Senior Past-President of the Institute, was made a member of the Privy Council in 1906, and in 1907 was raised to the peerage. He was an Original Member of the Institute, was elected a Member of Council in 1878, became Vice-President in 1879, and was President from 1889 to 1891. For his many services to metallurgy he was awarded the Bessemer Gold Medal in 1902. Baron Fernand d'Huart was the founder of the great steelworks at Longwy, and was also a director of numerous other important French ironworks. He became a member of the Institute in 1880, and was among the first Honorary Vice-Presidents elected under the new bye-laws in 1909. Mr. Hurry Riches was elected a member in 1898, having on the occasion of the visit of the Institute to Cardiff in 1897 acted as Honorary Secretary to the Reception Committee. He was a Past-President of the Institution of Mechanical Engineers and of the South Wales Institute of Engineers, and was a Governor of the Imperial College of Science and Technology. Sir John Aird, Bart., the well-known contractor for the Assouan Dam, had been a member of the Institute since 1887, and in 1906 he served on the General Reception Committee formed to receive the members of the American Institute of Mining Engineers on their visit to this country. General Salvador Díaz Ordoñez was a distinguished artillery officer of the Spanish army. He commanded the division of the Spanish army which occupied Melilla during the disturbances in Morocco last year, and on October 14 was fatally wounded in a skirmish near that town. It will be remembered that he attended the Autumn Meeting of the Institute held at Buxton in 1910. Particulars of the careers of these and other members deceased will be found in the obituary notices published in the Journal of the Institute.

In consequence of the non-payment of subscriptions, the names of thirty-eight members have been removed from the list, and there have been forty-three resignations of membership.

FINANCE.

The statement of accounts for the year 1911, verified by the Auditors, is now submitted by the Honorary Treasurer. It will be observed that the income for the year amounted to £6398, and the expenditure to £6625. The excess of expenditure over income is due to certain liabilities incurred on behalf of the members who intended to take part in the proposed Autumn Meeting in Italy. On the abandonment

of the Meeting the Council decided that the whole of these liabilities should be defrayed by the Institute. The corresponding figures of the receipts and expenditure in recent years are as follows:—

	Receipts.			Expenditure.		
	£	s.	d.	£	s.	d.
1906 . . .	6610	4	3	5915	11	8
1907 . . .	6454	16	3	5535	8	5
1908 . . .	6367	12	9	6011	15	5
1909 . . .	6356	10	0	5451	16	9
1910 . . .	6428	4	5	5811	18	9

MEETINGS.

During the year under review two meetings were held as usual. The Annual Meeting on May 11 and 12 and the Autumn Meeting on October 5 were held at the Institution of Civil Engineers in London, and the Council gratefully acknowledge the constant courtesy of that body in granting the use of their rooms.

It was originally intended that the Autumn Meeting should take place in Italy in 1911, an invitation to hold a meeting in that country having been received at the Annual Meeting of 1910. Extensive preparations were made by the President and Council of the Associazione fra gli Industriali Metallurgici Italiani, the prospective hosts of the Institute, in co-operation with other prominent personages in Italy, and under the illustrious patronage of His Majesty King Victor Emmanuel III. Most unfortunately, many of those who had originally intimated their intention to take part in the Meeting were compelled, for various reasons, to withdraw their names, and the number diminished so considerably that the Council felt that the representation of the Institute would be incommensurate with the scale on which the preparations for its reception had been made, and that, to their great regret, they had no option left them but to abandon the idea of holding the meeting in Italy. The arrangements for the visit had been kindly undertaken by Mr. G. E. Falck, President of the Italian Association, assisted by a strong Executive Committee of some of its leading members. Local Reception Committees had also been formed in each of the cities and towns which were to have been visited. Under the direction of Mr. Falck these Committees spared no effort to ensure the success of an extensive and attractive programme, and it was undoubtedly a source of

deep disappointment to them that ultimately the meeting did not take place. Details as to the constitution of the Reception Committee, and a brief description of some of the arrangements made, together with a reference to the handsome souvenir volume relating to the metallurgical industries of Italy, prepared for distribution on the occasion of the visit, have been embodied in the Journal. As a slight mark of appreciation of the generous services rendered by Mr. Falck, and by Mr. Casalbore and Dr. Gaddi, secretaries of the Association, the Council of the Iron and Steel Institute have since presented each of these gentlemen with a piece of silver plate suitably inscribed.

The Annual Dinner of the members of the Institute was held at the Connaught Rooms, Great Queen Street, on the evening of Thursday, May 11, the chair being occupied by the President. The principal speakers were Sir Hugh Bell, Bart., Past-President; the Most Honourable the Marquess of Bristol, M.V.O.; Major B. F. S. Baden-Powell; Mr. Arthur Cooper, Vice-President; the Right Hon. Lord Allerton, F.R.S.; Mr. J. S. Harwood Banner, M.P.; Sir H. Llewellyn Smith, K.C.B., and His Grace the Duke of Devonshire, President.

Twenty-six papers were contributed to the Institute's Proceedings during the year, together with a series of six memoirs on the iron ore resources of Italy, and are printed in the Journal, together with the discussions and correspondence thereon. The titles of these papers are as follows:—

1. "On Temperature Influences on Carbon and Pig Iron." By E. ADAMSON (Sheffield).
2. "On the Mechanical Influence of Carbon on Alloys of Iron and Manganese." By J. O. ARNOLD (Sheffield) and F. K. KNOWLES (Sheffield).
3. "On the Chemical and Mechanical Relations of Iron, Chromium, and Carbon." By J. O. ARNOLD (Sheffield) and A. A. READ (Cardiff).
4. "On Autogenous Welding of Metals." By F. CARNEVALI (Turin).
5. "On the Growth of Cast Irons after Repeated Heatings." By H. C. H. CARPLINTER (Manchester).
6. "On the Application of Electricity in the Metallurgical Industry of Italy." By R. CATANI (Rome).
7. "On the Influence of Impurities on the Corrosion of Iron." By J. W. COBB (Farnley).
8. "On the Magnetic Properties of some Nickel Steels, with some Notes on the Structures of Meteoric Iron," By E. COLVER-GLAUERT (Berlin-Charlottenburg) and S. HILPERT (Berlin-Grüneberg).
9. "On a Process for the Desiccation of Air by Calcium Chloride." By F. A. DAUBINÉ (Auboué) and E. V. ROY (Auboué).
10. "On the Present State of the Iron Industry in Italy." By L. DOMPÉ (Milan) and F. S. PUCCI (Milan).
11. "On the Volumetric Estimation of Sulphur in Iron and Steel." By T. GIFFORD ELLIOT (Sheffield).

12. "On the Origin of the Iron Ores of Swedish Lapland." By L. L. FERMOR (Calcutta).
13. "On the Action of Aqueous Solutions of Single and Mixed Electrolytes upon Iron." By J. NEWTON FRIEND (Darlington) and J. H. BROWN (Darlington).
14. "On New Industrial Processes for the Case-hardening of Steel." By F. GIOLITTI (Genoa).
15. "On Case-hardening by Means of Compressed Gases." By F. GIOLITTI (Genoa) and F. CARNEVALI (Turin).
16. "On the Transformations of Steel within the Limits of the Temperatures employed in Heat-treatment." By L. GRENET (Paris).
17. "On Iron-Silicon-Carbon Alloys." By W. GÖTTLICH (St. Gallen).
18. "On the Influence of Vanadium upon the Physical Properties of Cast Irons." By W. H. HATHFIELD (Sheffield).
19. "On the Organic Origin of the Sedimentary Ores of Iron and of their Metamorphosed Forms, the Phosphoric Magnetites." By W. H. HERDSMAN (Glasgow).
20. "Researches on the Nature of the Phosphates contained in Basic Slag derived from the Thomas-Gilchrist Process." By V. A. KROLL (Luxemburg).
21. "On some Studies of Welds." By E. F. LAW (London), W. H. MIRRETT (London), and W. POLLARD DIGBY (London).
22. "On the Corrosion of Metals." By P. LONGMUIR (Sheffield).
23. "On some Properties of Heat-treated Three per Cent. Nickel Steels." By A. MCWILLIAM (Sheffield) and E. J. BARNES (Sheffield).
24. "On the Influence of 0.2 per Cent. Vanadium on Steels of varying Carbon Content." By A. MCWILLIAM (Sheffield) and E. J. BARNES (Sheffield).
25. "On Mechanicalising Analysis as an Aid to Accuracy and Speed for Commercial Purposes." By C. H. RIDSDALL (Middlesbrough) and N. D. RIDSDALE (Middlesbrough).
26. "On the Welding up of Blowholes and Cavities in Steel Ingots." By J. E. STEAD (Middlesbrough).
27. Reports on the Iron Ore Resources of Italy:—
 - (a) "On the Production of Iron Ores in the Brembana Valley." By G. CALVI (Bergamo).
 - (b) "On the Iron Mines of the Island of Elba." By C. CAPACCI (Florence).
 - (c) "On the Iron Ore Deposits of Piedmont." By R. CATANI (Rome).
 - (d) "On the Iron Ore Deposits of Central Italy." By A. CIAMPI (Florence).
 - (e) "On the Iron Ore Deposits of Southern Italy and Sicily." By G. LA VALLÉE (Rome).
 - (f) "On the Iron Ore Deposits of Sardinia." By L. TISIA (Iglesias).

PUBLICATIONS.

The publications of the Institute during the past year have exceeded in bulk those of any previous year since its foundation. They comprise four cloth-bound volumes containing, together with the list of members, no less than 2660 pages of printed matter. Of these volumes, two belong to the ordinary series of the Journal and one to the Carnegie Research Memoirs, which contains the eight Carnegie Scholarship Reports submitted during the year under review. The remaining volume was a Decennial Subject and Name Index to the

publications of the Institute during 1901-1910. It contains 553 pages, and comprises a classified list of all the papers presented to the Institute during the preceding decade, together with an historical note of the development and growth of the Institute. This Index, notwithstanding the labour it involved, was published within five months of the appearance of the last volume of the Journal for the period to which it refers. The volumes of the Journal contain, in addition to the papers read at the spring and autumn meetings, and the discussions and correspondence arising therefrom, abstracts and references to over 2000 articles and memoirs relating to the iron and steel industries published in the transactions of kindred institutions and societies at home and abroad, and in the technical press of this country and of the principal foreign countries engaged in the industry. In the collection and compilation of these abstracts over 300 different periodicals have been systematically searched, and the information contained therein thus rendered accessible to the members of the Institute. Most of the original sources of information are filed in the Institute Library, where members are able to avail themselves at first hand of the information they contain. A list of these periodicals is published in the Journal of the Institute, which also contains reports of the various congresses held from time to time, a bibliography of works dealing with iron and steel which have appeared during the year, a list of the additions to the Library, and obituary notices of deceased members of the Institute.

LIBRARY AND OFFICES.

The attendance in the Institute Reading Room and Library during the year has been close on 800, and the Council are gratified to feel that the facilities placed at the disposal of the members are becoming more generally appreciated in proportion as they are more widely known. A number of works of reference have been presented, amongst which have been "Metallurgy: A Text-Book for Manufacturers, Foremen, and Workers in the Metal Industries," by A. Fenchel, translated by H. J. Morris, and presented by the publishers, Messrs. John Bale, Sons & Daniellsson; "The Corrosion of Iron and Steel," by Dr. J. Newton Friend, presented by the author; "Trempe, Recuit, Cementation, et conditions d'emploi des Aciers," by Mr. L. Grenet, presented by the publisher, Mr. C. Beranger; "Die Metallurgie des Wolframs," by Hans Mennicke, presented by Messrs.

von Krayn; "Our Home Railways," by W. J. Gordon, presented by the Secretary; and "Iron and Steel, their Production and Manufacture," by Christopher Hood, presented by Messrs. Isaac Pitman and Sons, Limited. The acquisitions by purchase have included, amongst others, various Parliamentary papers and reports, the Proceedings of the International Congress of Applied Chemistry, 1909; "The Basic-Open-hearth Steel Process," by Carl Dichmann; "A Pocket Encyclopædia of Iron and Steel," by Hugh P. Tiemann; and "La Métallographie appliquée aux Produits Sidérurgiques," by Umberto Savoia. Arrangements are in progress for rendering the works of reference in the Institute Library more readily available to members.

Members who have published works valuable for reference, or pamphlets on subjects relating to iron and steel, of which they could present copies, are reminded that such contributions to the Library are not only highly acceptable for permanent preservation, but are also useful for editorial purposes in connection with the Journal, and for compiling information in response to inquiries addressed by members and others to the offices of the Institute.

MEDALS AND RESEARCH SCHOLARSHIPS.

The Bessemer Gold Medal for 1911 was awarded to Mr. Henry Le Chatelier, Membre de l'Institut de France, in recognition of his eminent services in the advancement of the metallurgy of iron and steel.

The Andrew Carnegie Gold Medal for 1910 was awarded to Mr. Félix Robin, Paris, for his investigations on the variation in the acoustic properties of steel with changes of temperature, and his report on the microscopical examination of the depression made on steel by a conical point. Applications were received early in the year from thirty-six candidates desirous of competing for the Carnegie Research Scholarships. The cosmopolitan nature of this competition may be appreciated from the fact that seven applications were received from candidates living in the United Kingdom, five from Austria, three from France, thirteen from Germany, two from Italy, five from the United States, and one from South Africa. After careful consideration of their respective qualifications, four scholarships, each of the value of £100, tenable for one year, were awarded, and two further grants of £50 were made to former recipients of

Scholarships to enable them to continue useful research work. The names of the successful candidates and particulars of the awards have been published in *Journal* No. 1 for 1911, and the usual notices containing the conditions under which the Scholarships are awarded, printed in eight languages, have been distributed in various countries. In order to guide prospective candidates in the selection of a subject for investigation, a list of subjects relating to the metallurgy of iron and steel, which in the opinion of the Council it is advisable to recommend for investigation, has been drawn up and circulated.

APPOINTMENT OF REPRESENTATIVES.

The President continues to represent the Institute on the General Committee of the Royal Society for Administering the Government Grant for Scientific Investigations. At the request of the Council he also consented to represent the Institute on the Organising Committee of the Optical Convention, to be held in London in 1912, but owing to the many calls upon his time he was unable to act as representative of the Institute on the Board of the National Physical Laboratory, and under these circumstances Mr. W. H. Ellis, in conjunction with Mr. J. M. Gledhill, was nominated by the President, and appointed by the Council to represent the Institute on that Board. Sir Hugh Bell, Bart., Past-President, has continued to act as representative on the Board of Governors of the Imperial College of Science and Technology. Mr. Arthur Cooper, President-Elect, and Mr. George Ainsworth, Vice-President, have represented the Institute on the Engineering Standards Committee, and Mr. William Beardmore, Vice-President, and Mr. George Ainsworth continue to serve as representatives of the Institute on the Technical Committee of Lloyd's Register of British and Foreign Shipping. Mr. W. H. Bleckly, Honorary Treasurer, has been re-appointed to represent the Institute on the Court of the University of Liverpool. Sir Robert A. Hadfield, Past-President, continues to serve in the same capacity on the Court of the University of Sheffield, and Lord Merthyr of Senghennydd, Vice-President, continues to serve as representative of the Institute on the Court of the Bristol University. Dr. J. E. Stead, F.R.S., Vice-President, has been appointed, conjointly with the Secretary to represent the Institute on the Committee appointed at the instance of the Society of Chemical Industry in connection with the forthcoming Eighth International Congress of Applied Chemistry, at which

Sir Hugh Bell, Bart., and Sir Robert Hadfield have consented to act as representatives of the Institute. In response to an invitation from the Swedish Society of Engineers and Architects, Mr. E. J. Ljungberg, Honorary Vice-President, kindly consented to represent the Institute on the occasion of the celebration of the Jubilee of the Society at Stockholm, and to present an address of congratulation.

APPOINTMENT OF HONORARY VICE-PRESIDENT.

The Council have unanimously elected Mr. Giorgio E. Falck (Milan) as Honorary Vice-President of the Institute, under Bye-law 9 (a).

ELECTION OF MEMBERS OF COUNCIL.

The retiring Members of Council, whose names were announced at the last meeting, were: *Vice-Presidents*—Mr. William Evans, Dr. J. E. Stead, F.R.S., and Sir John G. N. Alleyne, Bart. *Members of Council*—Mr. W. H. Hewlett, Mr. C. P. E. Schneider, Mr. W. H. Ellis, Mr. C. J. Bagley, and Mr. J. H. Darby. Sir John Alleyne having died in February, the Council have elected Mr. G. Ainsworth to the vacant Vice-Presidency thus arising. These gentlemen, who are all eligible, are presented for re-election at the Annual Meeting. Professor Thomas Turner and Professor J. O. Arnold having also been nominated for election as Members of Council, voting lists have been issued, as prescribed in Bye-law 11.

The PRESIDENT expressed his own regret and that of the Council that the Honorary Treasurer, Mr. W. H. Bleckly, was unable to be present by reason of indisposition.

The SECRETARY thereupon read the Treasurer's Report for the year 1911, which was as follows:—

“It is once more my duty to present to you the Yearly Statement of Accounts, and to review, as briefly as possible, the financial position of the Institute. The year 1911 proved an eventful one in our financial history. in that, owing to certain exceptional circumstances. the expenditure exceeded that of any previous year, whereas the receipts remained about normal in comparison with those of the last five years. As a consequence, the year was wound up with a deficit which has only twice been exceeded in the past. Nevertheless, taking all circumstances into consideration, I think you will agree with me that the position on the whole is a satisfactory one.

“As will be seen from the printed copies of the audited Accounts which have been distributed in the room. the expenditure in 1911 amounted roundly to £6625, and the receipts to £6398. I may explain at once that the deficiency of £210 on the General Account can be regarded as being entirely due to the liabilities incurred on behalf of the members who had intended to take part in the proposed Autumn Meeting in Italy. The causes which most unfortunately led to the abandonment of the Turin Meeting were fully explained at the meeting afterwards held at very short notice in London, and I only need now refer to the subject for the purpose of reporting that, in accordance with the Council's decision, the whole of the Autumn Meeting expenses. amounting to £644, have been defrayed by the Institute. Of this sum about £450 represents compensation paid to railway agents and hotel-keepers on account of engagements entered into which, in the ordinary course, would have been paid for by the individual members. The remainder was expended in making the usual preparations for a foreign meeting of the Institute, and represents approximately the ordinary cost of such an event.

“Another item of extraordinary expenditure, which you will notice, is the cost of the Decennial Index of the *Journal*, amounting to £415. The publication of this Index became due this year, and I am pleased to say that many expressions of appreciation of its usefulness have been received.

“The remaining items on the expenditure side call for little comment, as they do not vary greatly from the corresponding ones of previous years. The cost of publishing the *Journal* was £1487, which exceeded that of 1910 by £146, the increase being mainly accounted for by the cost of the translation of an exceptionally large number of foreign papers. On the other hand, the expenditure on the library, on office furniture, on the Annual Meeting, on postage, printing, and travelling, is lower in each case.

“Thus it will be seen that the total extraordinary expenditure incurred consists of an unexpected expense of £450 and an expected one of £415, together amounting to £865, and that the other ordinary expenses together amount to £5760, or about £50 less than the total expenditure in 1910.

“The revenue, as stated, amounted to £6398, or just £30 less than the revenue of 1910. Analysing the principal items, the entrance fees total £207, showing an increase of £18 over the previous year, whereas the receipts from annual subscriptions amount to £4192, showing a falling off of £97. The receipts from the sale of the *Journal* have continued to increase—a fact which affords a most satisfactory indication of the scientific value of the proceedings.

“The receipts from the Carnegie Fund did not quite meet the expenditure. The income was £1011, which amount, being derived solely from interest on the invested funds, does not vary appreciably from year to year. The expenditure in grants to scholars, printing, and translation of reports and clerical assistance, was £1028. There is, however, still held in reserve an accumulated balance of £47 which, after liquidating the deficiency of £17 on the year's working, leaves an amount of £30 to the credit of the fund, as shown in the balance-sheet. During the year under consideration no changes have been made in the invested funds of the Institute.”

THE IRON AND STEEL INSTITUTE.

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STATEMENT OF ACCOUNTS.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1911.

INCOME.		EXPENDITURE.	
For Entrance Fees	£207 18 0	By Salaries (including Overtime)	£1000 19 1
" Annual Subscriptions	4192 13 0	" Office Rent, Cleaning, &c.	714 0 4
" Life Compositions	91 10 0	" Library Books and Binding	72 2 10
" Journal Sales	361 11 1	" Office Furniture	30 17 11
" Interest on Investments	433 18 3	" Autumn Meeting	614 17 1
" Income Tax recovered	26 8 5	" Annual Meeting	55 18 0
" Bessner Medal Fund Interest	£15 1 8	" Journal Publishing Expenses :-	
Do.	0 18 8	Printing, &c.	£1060 2 4
Interest on Deposit	14 0 1	Do. Index	366 10 5
" Sundry Receipts	52 4 3	Abstracts	117 3 2
	2 3 3	Translations	140 10 0
	587 9 10	Postages	139 1 11
		Do. Index	49 7 2
Carnegie Scholarship Fund :-			1902 18 0
Interest on Bonds	£557 5 1	" Stationery and Printing (including printing List of Members and copies of Papers)	351 5 1
Do. Investments	95 6 10	" Postage and Receipt Stamps	90 0 5
Income Tax recovered	59 3 2	" Insurance	2 7 0
		" Bessner Medal Fund Expenditure—Gold Medal	15 5 0
Balance, being excess of Expenditure over Income :-	£210 7 4	" International Testing Association. —	
General Account	16 8 4	Subscription	£5 0 0
Carnegie Scholarship Fund		Other Expenses	7 8 11
		Telephone	12 8 11
		" Travelling Expenses	18 10 0
		" Auditor's Fee	36 15 10
		" Sundry Payments	12 12 0
			39 19 8
			5597 17 2
		Carnegie Scholarship Fund :-	
		Scholarships	£500 0 0
		Medal	15 5 0
		Printing and Stationery	5 8 3
		Do. Research Memoirs	359 18 4
		Postage do.	52 4 1
		Translations	51 5 9
		Advertising	7 1 11
		Salaries	52 0 0
		Postage (General)	3 0 4
		Sundries and Carriage	1 18 4
			1028 2 5
			£6625 19 7

STATEMENT OF ACCOUNTS.

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BALANCE-SHEET, DECEMBER 31, 1911.

LIABILITIES.		ASSETS.	
To Sundry Creditors:—		By Subscriptions in arrear, since received	
Journal Printing and Publishing	£180 6 10	Interest on Investments accrued, due 31st December 1911	£73 10 0
Journal Postages	63 3 8	Sundry Receipts	216 19 3
Library Books and Binding	19 9 11	Journal Sales, since received	1 1 6
Office Rent, &c.	179 16 10	Investment on account of Life Compositions	188 5 6
Printing and Stationery	35 0 8	North-Eastern Railway 3 per cent. Debenture Stock, cost	125 17 6
Office Furniture	19 14 5	Telephone Deposit	1 0 0
Sundry Payments	0 16 2	Cash at Banks and in Hand:—	
Entertainments Account	0 1 3	On Deposit Account	£2200 0 0
Autumn Meeting	4 1 3	On Current Account	£412 17 11
Carnegie Scholarship Fund:—		Less Account Carnegie Fund	1 17 6
Scholarships due, 1911	250 0 0	On Entertainments Account	111 0 5
do do, 1910	75 0 0	Secretary's Balance:—	0 1 3
Printing Memos	369 18 4	At Bank	95 11 2
Postage of do	42 4 1	In Hand	39 16 5
Carriage of Gold Medal	1 16 0		
Advertising	5 5 1		
			£746 9 3
Subscriptions in advance	1527 0 8	Carnegie Scholarship Fund:—	
Entrance Fee in advance	53 12 8	Interest on Investments accrued, due 31st	
Carnegie Scholarship Fund:—	2 7 6	December 1911, since received	17 13 5
Amount at Credit thereof 1st January 1911	£47 9 8		
Less Excess of Expenditure over Income for Year	16 8 4		
Iron and Steel Institute Capital Account:—			
Amount at Credit thereof 1st January 1911	£3126 7 1		
Less Excess of Expenditure over Income for the Year	216 7 4		
	£4529 16 5		£4529 16 5

INVESTED FUNDS OF THE INSTITUTE.

£274 North-Eastern Railway 4 per cent. Preference Stock, cost	£1,297	6	7
£788 North-Eastern Railway 4 per cent. Guaranteed Stock, cost	1,008	11	0
£79 4s. 5d., "E." Annuity, Sindh, Punjab, and Delhi Railway, expiring 1968 with a Sinking Fund to replace the amount of Stock, cost	1,000	0	7
£70 1s. 8d., "E." Annuity, Great Indian Peninsula Railway, expiring 1948, with a Sinking Fund to replace the amount of Stock, cost	1,267	6	0
£130 North-Eastern Railway Irredeemable 3 per cent. Debenture Stock, cost	1,254	17	6
£100 Buenos Ayres Great Southern Railway 4 per cent. Debenture Stock, cost	1,594	12	9
£100 Commissioners for the Port of Calcutta 4 per cent. Bonds, 1939, cost	982	10	0
£500 Trustees of the Port of Bombay 4 per cent. Bonds, 1939, cost	809	0	0
	£13,213	7	5

ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

£64,000 Pittsburgh, Bessemer, and Lake Erie Railroad 5 per cent. Gold Debenture Bonds.
 \$25,000 United States Steel Corporation 5 per cent. Gold Debenture Bonds.
 \$11,000 Represented by :—
 £2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock,
 purchased at a cost of £2261, 10s. 0d.
 Cash Balance uninvested, £1, 17s. 6d.

\$100,000

(Signed) W. H. BLOCKIN, *Hon. Treasurer.*
 G. C. LLOYD, *Secretary.*

I have examined the above Accounts with the Books and Vouchers of the Institute, and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Invested Funds as shown above.

(Signed) W. B. KEEN,
Chartered Accountant.

23 QUEEN VICTORIA STREET, LONDON, E.C., April 11, 1912.

BESSEMER MEDAL FUND.

£34 London and North-Western Railway 3 per cent. Debenture Stock.

The PRESIDENT, in moving the adoption of the Report and Statement of Accounts, said that it would be generally agreed that the Report was a satisfactory one, and that the Institute was continuing its work on sound and proper lines

Mr. WALTER DIXON (Glasgow) seconded the resolution, which was put to the meeting, and carried unanimously.

Mr. F. MILLS (Ebbw Vale) proposed a vote of thanks to the President and Members of Council. He thought it would be generally agreed that those who were charged with the conduct of the affairs of the Institute were well versed in the commercial and metallurgical interests of which it took cognisance, and he believed that those gentlemen enjoyed the full confidence of the members. It was suggested some time ago that the system of election to the Council should be altered, but he personally was not in accord with methods of popular suffrage, and he thought the Institute would do well to continue the methods of election of its officers which had prevailed in the past. He knew something of those methods, as their effect had been to exclude him from membership of the Council, which he thought might perhaps be accepted as a sufficient guarantee of their efficiency. He believed that all the members were satisfied with the services rendered by the President and Council, and he had great pleasure in proposing a hearty vote of thanks to them for the work which they had carried out.

Mr. E. H. SANITER (Rotherham) having seconded the resolution, it was put to the Meeting, and carried by acclamation.

The PRESIDENT, in replying, said: 'On behalf of my colleagues and myself I beg to thank you for the resolution which has been moved, seconded, and so warmly carried by the members present. It is a satisfaction to us to know that we have carried out our work satisfactorily and well, but I would like to say what a great debt of gratitude we all owe to our secretary, Mr. Lloyd, and to his staff for the excellent way in which their work has been carried out. It is now my

duty to ask Mr. Arthur Cooper to take the Chair of the Institute for the next two years. I think the Institute is extremely fortunate in securing the services of a gentleman of his capacity in the Chair. If he has one failing it is one that is common to nearly every member of the Institute, and that is that he has a great deal more work to do than any one man ought to be called upon to perform. Many of us, as I have said, are in the same position, and we are most genuinely grateful to Mr. Cooper, both for the services which he has rendered to the Institute in the past, and for those which he has shown his readiness to carry out by taking the Chair of the Institute. I am sure that he will find the work extremely pleasant, and I am confident that the great traditions of the Institute may be safely entrusted to his hands."

Mr. ARTHUR COOPER then took the Chair, and said: "My Lord Duke and Gentlemen, I thank your Grace exceedingly for the very kind words which you have used, and I thank you, gentlemen, for the very cordial reception which you have given me. I am sure I need not say that no effort will be wanting on my part to maintain the present high status of the Iron and Steel Institute."

AUTUMN MEETING IN LEEDS.

The PRESIDENT then announced that the Autumn Meeting of the Iron and Steel Institute would be held at Leeds on Tuesday, Wednesday, and Thursday, October 1, 2, and 3. Arrangements were in progress for the formation of a Reception Committee in that city. No meeting had been held in Leeds since 1876, and he hoped that the members would do their best to attend and so contribute to its success.

BESSEMER GOLD MEDAL.

The PRESIDENT said that his first duty should have been the presentation of the Bessemer Gold Medal for 1912, which had been awarded to Mr. John H. Darby for the services he

had rendered in the advancement of the metallurgy of iron and steel. He regretted that Mr. Darby was not present to receive the medal in person, and his brother, Mr. William Darby, who was to have received it on his behalf, was also unable to be present, and had sent a message expressing his regret. Under those circumstances the actual presentation of the Medal would take place at a future meeting.

Mr. JOHN HENRY DARBY, to whom the Bessemer Gold Medal of the Iron and Steel Institute for the current year has been awarded, is a direct descendant of the distinguished family of metallurgists whose name he bears. Mr. Darby's connection with the iron and steel trades is best known from his association, as far back as in the year 1880, with the late Sidney Gilchrist Thomas, and the introduction of the basic process. The first basic open-hearth furnaces for the manufacture of steel on a large scale erected in Great Britain were those built under Mr. Darby's superintendence at Brymbo. Difficulties of a practical nature having been met with as regards recarburisation of the metal, Mr. Darby devised a process for the recarburisation of the metal in the ladle. He was also associated with the introduction in this country of by-product coke-ovens, and was the first to erect retort coke-ovens at ironworks. He has contributed a number of valuable papers to the Proceedings of the Iron and Steel Institute.

The PRESIDENT then delivered his Presidential Address, the text of which will be found on page 31.

His Grace the DUKE OF DEVONSHIRE said he was sure it would be the wish of the members, as it was his own to express their grateful thanks to the President for the extremely interesting and valuable Address which he had given them. They owed him a great debt of gratitude for having placed before them in so clear a way the tremendous evolution which had taken place in the manufacture of steel. Mr. Cooper had quite clearly shown that in the period covered by his own observations the whole conditions of the industry had changed, and the only conclusion that could be drawn from the Address was that it was never safe to prophesy. There might be greater changes still to come in the steel industry,

and it was necessary that British steel-makers should take care that they were not left behind in the race. But with men like the President to apply themselves to the problems which had to be solved, there was no need to fear the result. It was to the reading of Papers on the lines of the Presidential Address that they looked forward to holding their position in the manufacture of steel. He begged to move that the best thanks of the Institute be given to Mr. Cooper for his Address.

Sir HUGH BELL, Bart., Past-President, said that he had great pleasure in seconding the vote of thanks. Mr. Cooper at the outset of his Address had expressed his intention of making a review of the heavy steel trades for the past forty years or thereabouts, and they were very grateful to him for putting on record in so clear a way the extraordinary evolution which had taken place within a period of forty odd years. He felt quite certain, however, that many of the members would regret that Mr. Cooper, by embodying his statements as a Presidential Address, had raised them above discussion. There was a very good rule that they were not permitted to discuss the contents of a Presidential Address, and the President was no doubt fully aware of that when he was engaged in the preparation of it, and was able to trail his coat-tails, knowing full well that no one would dare to tread upon them. He (Sir Hugh) could, if he would, tread upon them, and no doubt there were many other members of the Institute in the same position. It was, however, extremely interesting to have placed on record the changes which had taken place in the trade during the past forty years. One comment at least he would venture to make, as it did not tread on the tails of the President's coat at all. In one part of his Address the President referred to the unreasonable conduct of owners possessing ores containing phosphorus. The time was when a little reduction in price was made for such ores, and steel-makers had continued to obtain that reduction as long as they could. Unfortunately, the owners of these ores had now discovered that phosphorus was a valuable ingredient, and they made the steel-makers pay for it. He was glad that attention

had been called to it, and that there had been a holding-up to obloquy of those who persisted in that most unreasonable course of conduct! Then he noted that the President departed somewhat from the lines he had himself laid down, as he had not merely reviewed the past, but had endeavoured to look into the future as far as lay within the power of man so to do, and their thanks were due to the President for having placed upon record the story of the past, and for having attempted to forecast the prospects of the trade in the future. Ten years hence, perhaps, somebody in the same position as Mr. Cooper occupied that day would be considering what to say to the members of the then Institute, and he would no doubt look back to Mr. Cooper's Address, and point out how well he had foreseen what was going to take place in the future. The remarkable thing about the steel trade as their President had known it, was the extraordinary manner in which what were once regarded as only subordinate sections of the industry had gradually come forward into a position of great prominence. Only the other day he had had occasion to observe that a visitor going round a steelworks would hardly notice the steel, which was to a certain extent dwarfed by the important processes for the utilisation of what were formerly regarded as useless and deleterious bye-products. They owed the President their very hearty thanks. He ventured to suggest that in no respect did they owe him more thanks than for recalling to their recollection the very significant words of his predecessor in the chair, their old colleague and friend Mr. Martin who foresaw what was now taking place fifteen years ago, and he believed that in their turn they would look back to the prognostications made by Mr. Cooper which he hoped would be as well realised as those of his predecessor in the chair.

Mr. WILLIAM HAWDON (Middlesbrough) supported the vote of thanks to the President for his Address. They were all pleased that Mr. Cooper had been persuaded to lay aside his modesty, and to accept the position of President when asked to do so by the Council. He believed that in the future they would look back to that Address with great interest.

The vote was then put to the meeting and carried by acclamation.

The PRESIDENT, in reply, said he was extremely gratified at the way in which they had received his Address. He had prepared it with a great amount of trepidation, because he had the feeling in his mind that whatever he said would be known to at least half the members in the room. He was glad to conclude from the vote they had passed that his Address had been well received, and he hoped that that kindly reception might be taken as an indication of the indulgence which would be extended to him during his term of office.

Papers by Dr. H. Nathusius, Dr. J. E. Stead, F.R.S., Sir Hugh Bell, Sir Robert A. Hadfield, F.R.S., and Professor Thomas Turner were then read and discussed, the meeting being adjourned at 1 P.M. until 2.30 P.M. on the same day.

Sir ROBERT HADFIELD, F.R.S., Past-President, presided at the afternoon meeting, when papers by Dr. J. O. Arnold, F.R.S., and Professor A. A. Read, Dr. Arnold and Mr. L. Aitchison, Dr. J. N. Friend, Mr. J. Lloyd Bentley, and Mr. W. West, and Mr. C. Chappell were read and discussed, the meeting being adjourned until 10.30 A.M. on the following day.

AWARD OF CARNEGIE GOLD MEDAL AND RESEARCH SCHOLARSHIPS.

On the resumption of the meeting on Friday, May 10, the PRESIDENT made an announcement regarding the Carnegie Awards. He said that in order to allow more time to consider the merits of the researches for the award of the Carnegie Gold Medal, the Council had decided that the award should be made in the year following that in which the Report was received. The Carnegie Gold Medal had been awarded by the Council to Dr. Paul Goerens for his Report of the previous year. He would like to point out that the Council had experienced considerable difficulty in making the award, owing to the highly meritorious character of the Reports received, and they would

have been pleased if they had had seven Gold Medals to distribute instead of one. They ultimately came to the conclusion that the most meritorious of the seven Reports received, was that by Dr. Paul Goerens.

In making the presentation to Dr. Goerens, the President expressed the pleasure with which that Medal was bestowed. He said that Dr. Goerens had carried out admirable research work, and had made many valuable contributions to scientific literature.

The SECRETARY announced that the Council had decided to award the Andrew Carnegie Scholarships for 1912 to the following applicants: £100 each to Mr. Arthur Kessner of Berlin, Mr. Eugène Nusbaumer of Loncin-lez-Liège, Belgium, and Mr. J. Allan Pickard of Woolwich Arsenal. It was stated that a similar award had been made to Mr. Walter S. Landis, formerly of Lehigh University, but that Mr. Landis had had to decline the award, as he had left the University, and was now occupying a position which would prevent him giving the necessary time to the research work.

The SECRETARY also announced that a further grant of £50 had been made to Mr. J. C. W. Humfrey, of the National Physical Laboratory, Teddington.

The following are brief notes of the careers of the recipients of the Carnegie Gold Medal for 1911 and Research Scholarships of the Iron and Steel Institute for 1912:—

DR. PAUL GOERENS, to whom the Andrew Carnegie Gold Medal has been awarded, was born in 1882, and was educated at Luxemburg and at the Royal Technical College of Aix-la-Chapelle. His practical training was obtained at Differdingen. He became a Doctor of Engineering in 1906, and was awarded the title of Professor in 1909. He is Demonstrator in Physical Metallurgy, Materials, and Fuels at the Royal Technical College, Aix-la-Chapelle. He was awarded a Carnegie Scholarship grant of £100 in 1910 to enable him to pursue his investigations on the influence of cold working on the properties of iron and steel, and it is for the results obtained in connection with this research that the Gold Medal has been awarded to him.

ARTHUR KESSNER was born in 1879, and educated at Potsdam and at the Royal School for Machine Construction at Hagen. He was subsequently engaged practically at the State Railway Central Works at Potsdam, after which he studied metallurgy at the Royal Technical High School, Charlottenburg, where he was appointed permanent assistant to the Chair of Mechanical Technology. Since 1907 he has held the appointment of Constructional Engineer at the High School, and lecturer in Mechanical Technology at the "Urania," Berlin. He receives an award of £100.

EUGENE NUSBACMER was born in 1882, and educated at the University of Paris and at the Institute of Applied Chemistry in the same city. He is chief chemist at the works of G. Perihon at Loncin-lez-Liège, Belgium. He has carried out investigations on the wear of metals and on alternating stresses, and contributed a memoir at the Copenhagen Congress of the International Testing Association on the latter subject. He receives an award of £100.

J. ALLEN PICKARD was born in 1886, and educated at the City of London School and at the Royal College of Science, where he obtained the Associateship. He is research chemist in the metallurgical branch of the Research Department of Woolwich Arsenal. He graduated with honours as a Bachelor of Science of London University, and is a Fellow of the Chemical Society. He has carried out investigations in organic chemistry, and has devised a method for the estimation of oxygen in iron and steel. He receives an award of £100.

The PRESIDENT announced that Mr. Charles Vattier, a member of the Institution of Civil Engineers of France and Delegate of the Chilian Government, was in attendance, and would, during the course of the morning, deliver an address in an adjoining room on the metallurgical resources of Chile, with special reference to the ore deposits of that country. Mr. Vattier had travelled from Chile for the express purpose of laying before the members of the Institute information relative to those resources; and although unfortunately, he had not been able within the statutory time to present a paper for reading at the meeting, he had prepared copious notes which, illustrated by maps, diagrams, and samples of the actual ores themselves, would doubtless prove of much interest to many of the members.

Papers by General L. Cubillo, Mr. J. W. Hall, Mr. E. G. Herbert, and Mr. F. Roger were then read and discussed.

VOTES OF THANKS.

The PRESIDENT said that they had now concluded the ordinary business of the meeting, and all that remained was to propose a hearty vote of thanks to the President and Council of the Institution of Civil Engineers for their renewed kindness in granting them the use of the rooms for their Annual Meeting. He believed that that would be the very last time they would meet in that room, because the building was about to be taken down. They had enjoyed the hospitality of the Civil Engineers for many years: in his own case it must have been thirty-four or thirty-five years since he attended his first meeting there. In that particular room their meetings had been held for twenty years. They thanked the Council for past and present favours, and might possibly express the hope that in the new building to be erected they might enjoy a continuance of the privileges so long accorded to them through the kindness of the President and Council of the Institution of Civil Engineers.

Mr. G. AINSWORTH, Vice-President, in seconding the vote, said the destruction of the building meant the breaking up of one more old association, a severance which, as they got older, they appreciated less and less.

The resolution was carried unanimously.

Professor HENRY LOUIS (Newcastle-on-Tyne) said it was his pleasant duty to propose a cordial vote of thanks to their President, Mr. Cooper, for his conduct in presiding over their meetings. He thought that the commencement made was the best possible augury for the continued success of the President's term of office.

Mr. RALPH G. SCOTT (Leeds), in seconding the vote, said that he thought the proceedings had been a little more con-

versational, and rather less formal than for the past year or two. Personally he was exceedingly pleased to second the vote of thanks to Mr. Cooper.

The vote was then put to the Meeting, and carried by acclamation.

The PRESIDENT said he was extremely obliged to the members for the way in which they had received the resolution. He could assure them that his office had furnished him personally with a great amount of pleasure, and if they were satisfied he was more than delighted. He felt that they had treated him with a great amount of indulgence and forbearance, and he hoped he might rely upon that during his period of office.

The proceedings then terminated.

PRESIDENTIAL ADDRESS.

BY ARTHUR COOPER.

BEFORE entering on the subject-matter of my address, I desire to place on record my sincere appreciation of the very high honour you have conferred upon me in electing me your President. At the same time, I should like it to be understood that I accepted nomination with great hesitancy, not because I was unmindful of the kindness of the Council, but because I feared it would not be possible for me to discharge the responsible duties of the office in a way satisfactory to myself, or in a way that would compare with the discharge of those duties by the illustrious men who had preceded me. I was, however, influenced by the assurance of my colleagues that I might depend upon their cordial assistance and support, and on this I feel I can rely.

As the years roll on, the selection of a theme for an address to a society like the Iron and Steel Institute becomes increasingly difficult, and one is forced to choose between a special subject that can be interesting to a portion only of the members, or one of more general interest upon which much has already been said.

After mature consideration, I decided on the latter, and propose to review the development of the heavy steel industry during the forty years I have been associated with a branch of it.

By "heavy steel industry" I mean the Bessemer and open-hearth processes and their modifications.

I am conscious that this subject has been dealt with in detail by members, who have described their various inventions in papers read before this Institute, and in a general way by several of my predecessors, but some years have elapsed during which great improvements have been made both in methods and in plant. Whilst, therefore, little remains to be said concerning the processes as originally carried

out, I am hoping that a brief reference to some of the improvements that have taken place in recent years may be of interest. as these have had the effect of very greatly increasing the output, decreasing the cost, and improving the quality of the products.

If, in my review, I do not appear to specially advocate any particular process or form of plant, it is because my sincere wish is to treat the subject in a perfectly fair and impartial manner by giving facts as they present themselves to me, and by leaving it to others to draw their own conclusions.

1870.

In the year 1870, when the acid Bessemer process was fully established and the open-hearth process had just been introduced, the make of ingots in the world was as follows:—

Great Britain.	Germany.	France, 1869.	U.S.A.	Austria-Hungary.	Sweden.	Belgium.	Total.
Tons. 250,000	Tons. 170,000	Tons. 97,284	Tons. 38,840	Tons. 22,112	Tons. 12,193	Tons. 9,563	Tons. 599,992 ¹

¹ Say about 600,000 tons.

These ingots were for the most part acid Bessemer, and the purpose for which they were used was chiefly rails.

In those early days, even in works producing their own pig iron, the steel department was operated quite independently of the blast-furnaces and of the rolling-mills; none but the purest hæmatite pig iron was used. This was carefully selected by fracture, and, where more than one make was introduced, charges of the weight required were made up of a mixture of the different brands, so as to correct variations in any individual brand: and if for conversion by the Bessemer process, each charge was melted down in a separate cupola at a great cost in coke; the ingots produced were allowed to cool down, and afterwards heated horizontally in small coal-fired furnaces preparatory to their being hammered into blooms or slabs, which, after inspection and dressing cold, were again heated and rolled into finished articles.

There was no organised laboratory control of the materials used, and the estimation of carbon by colour in a sample taken from the blow or charge usually constituted the only chemical test.

A very large percentage of the ingots made were more or less red-short, often due to the irregular contents of manganese in the spiegel, which would have been detected and the unsatisfactory results prevented with efficient laboratory supervision.

Notwithstanding everything, excellent steel was produced from those ingots, that could be coaxed down into respectable blooms. The cost, however, compared with the present practice, in fuel, wages, and waste, was enormous. The output of a pair of acid-lined converters was about 600 tons per week, and this quantity was considered a very fair week's work for a rolling-mill.

1871 to 1880.

Early in this decade the blooming- or cogging-mill took the place of the hammers, and with its aid some steel-makers, recognising the importance of saving fuel, delivered their ingots singly, and as hot as possible, to the mill-heating furnaces, from which they were rolled off at one heat direct into rails; and at works where blast-furnaces existed, molten iron was taken direct to the converters. Other outlets were found for the steel, such as for ship- and bridge-building and for tinplates; but probably the most important development during this period was the discovery and establishment of the basic process, which was destined to render available for steel-making purposes, in all parts of the world, immense tracts of ore beds, which, by reason of their high content of phosphorus, could not be used for steel-making by the acid processes.

The output of ingots in the world in 1880 is given in Table I., p. 48.

Of the 4,000,000 tons of ingots produced in 1880, it will be noted that upwards of 80 per cent. were made by the acid Bessemer process which had been developed very rapidly

during the ten years ending 1880, not only in Great Britain, but also in the United States Germany, France, and Belgium.

1881 to 1890.

During the above period the basic open-hearth process was established, and bye-product coke-ovens were first put down as adjuncts to blast-furnaces, as it came to be recognised not only that the bye-products reduced the coke cost, but also that the waste heat and waste gases could be converted into steam, and turned to useful account at the adjoining iron and steel works.

Mr. Gjers also demonstrated that when the ingot, immediately after casting, was placed in a vertical pit lined with firebrick and allowed to soak, there was sufficient heat in it to enable it to be rolled into blooms and billets or rails. The steel trade is greatly indebted to Mr. Gjers for the economies he introduced in the handling of ingots preparatory to rolling, as undoubtedly from his pits and methods originated the vertical ingot furnaces of to-day, in which the centres of the ingots set whilst in an upright position, thus avoiding the tendency to bleed and cause hollow products, which frequently happened when they were turned on to their sides soon after they were cast, for heating in the horizontal furnaces of former times.

After numerous experiments on the Continent and also in this country it was abundantly clear that the phosphoric slag from the basic converters, when ground into an impalpable powder, had a high manurial value. It must not, however, be imagined that this discovery was immediately turned to profitable account. Considerable difficulties were met with in grinding it satisfactorily, chiefly on account of the shots of steel with which it was interspersed.

The first attempts made with stone mills as formerly used for grinding corn proved utter failures, and it was only after many months of costly and tedious experiments that a satisfactory solution of the problem was arrived at and the slag could be ground regularly into a fine powder at a sufficiently

low cost to enable it to compete with super-phosphate and leave a margin of credit to be placed against the ingot.

The revenue so derived from this ground slag has aided very considerably in the development of the basic processes, as will appear later.

Captain Jones, in America, and Mr. Gustav Hilgenstock, in Germany, about the same time, and quite independently of each other, demonstrated the great advantage of mixers or receivers between the blast-furnaces and the steel-converting plant.

I had the honour on May 9, 1895, of reading a paper before this Institute on this subject.

The output of ingots in the world in 1890 is given in Table II., p. 48.

It will be seen that from the years 1880 to 1890 the make of ingots of the world had increased from 4,000 000 tons to 12,000,000 tons, the most notable increases being in the production of acid Bessemer steel in the United States, of acid open-hearth in this country, and of basic Bessemer in Germany.

1891 to 1900.

Between 1891 and 1900 great improvements in appliances, and several important inventions, were introduced, such as the use of electricity for the driving of auxiliary machinery in iron and steel works, and also for driving small rolling-mills; Mr. Saniter's method of desulphurising; Messrs. Bertrand & Thiel's modification of the open-hearth process; and the use of blast-furnace gas as a motive power, first by Mr. James Riley and Mr. B. H. Thwaite, in Glasgow, followed very shortly by Mr. Greiner in Seraing. Mr. Talbot also introduced his method of working the open-hearth process continuously, and the Hon. Charles A. Parsons and Professor Rateau developed their steam and exhaust steam-turbines.

The output of ingots in the world in 1900 is given in Table III., p. 49.

The most striking features of the figures in Table III. are the large increases since 1890 in the production of ingots in the United States, viz., from 4,000,000 to 10,000,000 tons,

of which 6,500 000 were acid Bessemer, and 2 500,000 tons basic open-hearth; and in Germany from 2,000,000 tons to 6,500,000 tons, of which 4,000,000 tons were basic Bessemer and 2,000,000 tons basic open-hearth.

1901 to 1910.

Whilst it cannot be said that these ten years were years of invention and novelties as were the thirty years preceding, great improvements have been made both in methods and in the perfecting of plant and appliances introduced during the latter part of the last century. Amongst the former may be mentioned the very important work of the Engineering Standards Committee—the father of which was its present chairman, Sir John Wolfe Barry. The main committee consists of delegates of the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, and the Institution of Electrical Engineers; and during the last ten years this committee, with its thirty-nine sectional and sub-committees, and with the aid of its able secretary, Mr. Leslie S. Robertson, have dealt with a very great variety of subjects, that immediately concerning this Institute being the standardisation, both for sizes and tests, of materials of all rolled sections as used for constructional purposes for ship- and bridge-building and boilers, as well as for railway and tramway rails and fishplates, and for tyres and railway rolling-stock.

The effect has been to reduce enormously the number of sections called for, as, owing to the very representative and influential character of the committees, British standard sections and specifications have been very extensively adopted, notably by the Admiralty, the Board of Trade, and Lloyd's Register. The British Corporation for the Survey and Registry of Shipping and the Bureau Veritas have likewise given effect to the committee's recommendations in their rules, with the result that the cost of roll stocks is being greatly reduced, and the manufacturer may now be content to roll into stock when it suits his convenience to do so, with the certainty that he will not have the material left on his hands as was formerly

frequently the case when almost every buyer had his own particular section and specification, which no other buyer could be prevailed upon to take. The advantage to the consumer of the adoption of the standard sections being quicker delivery (small lots frequently from stock) and reduced cost practically no special rolls being now required.

The output of ingots in the world in 1910 is given in Table IV., p. 49.

Comparing the production given in Table IV. of the three largest steel-producing countries for 1910 with the production of the same countries for 1900 (Table III.) it will be seen that—

In the United States, whilst the make of acid Bessemer ingots has increased from 6,500 000 tons to 9 500,000 tons, the make of basic open-hearth ingots has increased from 2,500 000 tons to 15,000,000 tons.

In Germany, whilst the make of basic Bessemer ingots has increased from 4 000 000 tons to 8,000 000 tons, the make of basic open-hearth ingots has increased from 2,000,000 tons to 5,000,000 tons.

In Great Britain the only notable increase has been in basic open-hearth ingots, viz. from 300,000 tons to 1,500 000 tons, the make of basic Bessemer and acid Bessemer and open-hearth being substantially the same as in 1900.

It will also be noted that in these three countries together the make of basic open-hearth ingots in 1910 represents rather more than half the entire make by all the processes, against rather less than one-quarter of the make in 1900.

In the United States the basic open-hearth process is assuredly taking the lead adapted as it is to produce pure steel of any quality from the softest to the hardest from ores too low in phosphorus to be utilised by the basic Bessemer process, and too high for either of the acid processes.

In Germany, on the other hand, while the basic open-hearth process is making great headway, very large increases of plant for the basic Bessemer process—by which soft and medium hard steel can be produced with great regularity and at very low cost—are being laid down, the phosphoric ores of Luxemburg and neighbouring districts producing a cheap iron eminently suitable for conversion into steel by this method.

In France, too, and in Belgium, where similar ores are available, the chief extensions which are being carried out at the present time are in plants for the basic Bessemer process, assisted as it is very materially by the revenue derived from the rich phosphoric slag which it produces.

The output of the world of such slag during 1910 was as follows :—

	Tons.
Germany	1,730,000
Great Britain	370,000
Belgium	360,000
France	335,000
Other Countries	105,000
	<hr/> 2,900,000

Practically the whole of this was ground and sold for fertilising purposes, and realised on the average about two pounds per ton delivered to the farmer, yielding to the steel-maker a credit of from four to six shillings per ton of ingots made, and, where the phosphorus in the ore is not paid for, reducing the cost of his ingot by this amount.

In Great Britain the acid processes at present are the largest producers and whilst there is no reason for supposing that so long as existing works can obtain pure hæmatite ores at reasonable prices there will be any serious falling off in the make of acid steels, the main and trusted products of this country for so many years, it is, I think, certain that because of the scarcity and of the increasing cost of these ores, future extensions of steel-making plant will be for the basic open-hearth process, which is not only capable of utilising all domestic phosphoric ores, but also foreign ores that can be imported at a low cost, too high in phosphorus for the acid processes and too low to command a value for the phosphorus for the basic Bessemer process—indeed, now that the supply of puddlers' tap is so limited and the owners of the rich phosphoric ores (by no means plentiful) have fully realised the worth of the phosphorus and insist on being paid full value for it, the cost of iron to the basic Bessemer steel maker in Great Britain is becoming too dear to enable him to compete with his open-hearth rival, and it seems probable that he will ultimately be driven to change his process for that of basic open-hearth or some modification of it.

I have thus endeavoured to show the gradual development of the chief steel-making processes in the different countries since 1870, and the Appendix gives the finished steel products for 1910 as far as the figures are available. I should now like to draw attention to some of the improvements that have taken place in methods and in plant, particularly during the later years and which have undoubtedly placed the industry in the position it now occupies.

In the early days it became apparent that an exact knowledge of the composition of all the materials used was essential, and the solitary works chemist of that period, who spent most of his time in estimating combined carbon by colour, has given place to a highly-trained and well-organised staff under a skilled chief, whose duties are to sample, analyse, and report upon incoming raw materials, as well as on all finished goods and waste products, to advise and assist the managers of the different departments in the various manufacturing operations so as to check waste and to ensure that everything possible is turned to useful account, and that nothing leaves the works that does not comply with the specification; and when steel-makers realised the great advantages in point of cost of using molten iron direct from the blast-furnaces, and that the utilisation of the waste heat and surplus gases from their coke-ovens in their steel works boilers reduced their coal bills, bye-product coke-ovens as well as blast-furnaces came to be regarded as necessary adjuncts to the steel works and most of the recently built large steel works, where conditions are favourable, are so equipped.

BYE-PRODUCT COKE-OVENS.

Bye-product coke as originally made in this country had a very uphill fight, chiefly because it was much softer than the excellent beehive coke then in use. Its density of late years has been much improved by building the ovens of a width most suitable for the coals and by varying the time of coking, and coke-makers who have had a lengthened experience maintain that by stamping the coal into a cake or block just large enough to fill the oven when pushed in, coke equal

to that from beehive ovens can be produced from equal coals—that charging in a cake or block can be effected more expeditiously than by tipping the coal into the oven from the top and afterwards levelling it; that there is less loss of heat and that a greater output per oven can be obtained.

The ovens as originally built provided a small surplus of heat and gas for purposes outside the requirements of the plant, but the modern regenerative ovens with their very economical methods of regulating combustion of the gas in flues, so as to obtain a perfectly uniform heating of the walls provide a surplus of fully 50 per cent. of the gas produced for outside uses, such as for furnace-heating, for lighting, or for power. This from a plant making 5000 tons of coke per week would mean upwards of 200,000 cubic feet of spare gas per hour, equivalent to, say, 8000 indicated horse-power if used in gas-engines, or to, say, 750 tons of coal per week if used for metallurgical or heating purposes.

Great improvements have also been made in the processes for the recovery of the tar and ammonia, giving better yields of bye-products and reducing the cost of working expenses and repairs.

BLAST-FURNACES.

The chief improvements which have taken place in blast-furnaces during recent years, following the use of larger volumes of air at higher temperatures, have been in the perfecting of the mechanical charging appliances so arranged that the materials can be uniformly distributed in the top of the furnace, at almost any speed required, at a very low cost in labour and in maintenance, and without any loss of gas when the bell is lowered, and also in the construction of the boshes and of the stacks, both now frequently cooled by water sprays or troughs, or by bronze or some other pattern of water-cooled blocks, by which means the life of the furnace-lining, which was shortened very considerably in the early days of rapid driving, has been materially increased; but probably one of the most important developments in connection with blast-furnaces has been the cleansing of the whole of the gases, for, not only has it been proved absolutely necessary

to use perfectly clean gas in the gas-engine, but it has been found very advantageous to rough clean also that used for stoves and boilers, as with such gas the necessity for laying off the stoves to remove the dust, with the consequential costly repairs, and the periodical stopping of the entire plant for clearing the dust from the flues can be avoided; further, by the use of clean gas the heats can be maintained in the stoves at a higher and more uniform temperature, reducing the consumption of coke, and since the cleaned gas has a higher calorific value less is required, so that more is available for outside purposes.

The two most favoured methods of blowing blast-furnaces to-day are by the reciprocating gas blowing-engine using blast-furnace or coke-oven gas, or by the steam-turbo blower, supplied with either high-pressure steam generated in boilers from similar gases, or with exhaust steam from rolling-mill engines—the turbine in this latter case being of the type known as mixed-pressure, which can be run with high-pressure steam at times when exhaust steam is not available. Both types of turbine depend for their efficiency upon perfect condensers and an ample supply of cold water.

In a blast-furnace plant producing say 5000 tons of iron per week, with a consumption of 20 cwt. of coke per ton, it has been established that by using modern gas blowing-engines and gas electrical generators for driving outside machinery, such as hoists, charging apparatus, and pumps, there would be sufficient surplus gas if used in gas-engines to generate say, 22,000 indicated horse-power, or, if used for heating or metallurgical purposes, equivalent to, say, 1600 tons of coal per week.

If, on the other hand, turbo-blowers and turbo-electric generators using high-pressure steam were employed instead of gas-engines, on the assumption that the turbine requires not more than double the quantity of gas required by the gas-engine, to supply it with steam, there would be sufficient surplus gas to generate, say, 7500 indicated horse-power or if used for heating or metallurgical purposes, equivalent to, say, 1150 tons of coal per week.

It is claimed for the modern gas-engine, adopted almost exclusively in Germany, France, and Belgium, to a consider-

able extent in recent installations in the United States, and in several large works in this country and in Canada that it can be operated with about 100 cubic feet of blast-furnace washed gas per effective horse-power per hour, and now that the weaknesses in design and construction, features of the earlier models, have been remedied, it is to-day a perfect machine, and quite as reliable as its predecessor, the reciprocating steam-engine—that the quantity and pressure of the blast delivered to the furnace from it is under much better control than from the turbo-blower.

It is claimed for the turbo-blower—used to a considerable extent in this country—and in a few plants only in the United States and on the Continent, that, although requiring at least double the amount of gas when burnt under boilers to provide it with steam, it is a cheaper plant to install, and by reason of its simplicity the cost of stores and maintenance is likely to be lower, that the blast is delivered continuously by it, and not intermittently, as by the reciprocating engine.

Surplus Gases.—At collieries and at blast-furnaces, where there are no iron or steel works depending upon heat, the surplus coke-oven gas is now frequently used for generating electricity for power and for light, and any such power and light beyond the actual requirements of the plant is sold outside, thus reducing the coal or pig iron cost. It appears to be the general practice on the Continent, and in the new installations in America and in Canada, where steel works form part of the plant, to use the coke-oven gases for metallurgical and for heating purposes, and the blast-furnace gases for the generation of power; yet there are many instances where blast-furnace gases are also used in mixers, open-hearth furnaces, and heating furnaces, with satisfactory results.

STEEL WORKS.

Mixers.—Since their introduction in 1889 the use and value of metal mixers has greatly increased. It soon became clear that the single mixer of about 150 tons capacity as originally erected was far too small, for whenever the demand upon it, even for a short time, was increased, or the supply

of molten iron was checked, the store was so much reduced that the metal often left the mixer of practically the same composition as it entered it probably only a few minutes before.

Again, the pig iron made over the week-end when the steel works were standing had always been a difficulty. It caused delay and extra cost when used cold in the open-hearth furnace, and excessive cost and waste when it had to be remelted in cupolas for use in the converters.

The problem of how to ensure more uniform iron for the steel plant, and how to save the cost of remelting the Sunday pig, has been solved by greatly increasing the mixer capacity, and most large works are now provided with either one or two or more mixers of from 400 tons to 1100 tons capacity, some of the simple cylindrical tank type without regenerators, but frequently supplied with coke-oven or blast-furnace gas burned over the top of the bath; the principal function of these—largely used on the Continent and in the United States—is to receive the week-end iron, and to maintain a large store during the week. Very little, if any, cold metal can be melted, and practically no change takes place in the composition of the bath, except that brought about by the admixture of the different ladles of iron from the different blast-furnaces.

Another design of mixer which finds most favour in this country, and which is also used in Canada, and France, and in Germany, is of the gas-fired regenerative tilting open-hearth furnace type. These serve not only the purpose of storing the week-end iron, but they will also melt up during the week large quantities of pig iron or scrap, thus obviating the use of cupolas altogether; and, further, by adding lime and ore, the contents can be refined down to almost any composition required with absolute regularity (a most important condition for the production of uniform steel), thereby reducing the work to be done in the converters and finishing furnaces, shortening the time of the operation, and increasing the life of the linings and the weekly output. This type of mixer, of course, involves extra cost in working over that of the simple cylindrical tank type, but it is held that the extra cost is more than compensated for by the advantages above mentioned.

Converting and Melting.—In the converting and melting departments great changes have taken place. Instead of the pair of 5- to 8-ton converters operated by steam blowing-engines from coal-fired boilers, with its wasteful adjunct the cupola plant, turning out from 600 to 800 tons of ingots per week, and instead of the 10- to 15-ton open-hearth furnace, with an output of 100 to 200 tons per week, will be found in the most recent plants from three to six 25- to 35-ton Bessemer converters, with an output of upwards of 10,000 tons of ingots weekly, operated by gas blowing-engines; and open-hearth furnaces of from 40 to 120 tons capacity, with a weekly output per furnace of from 600 to 1200 tons of ingots. Indeed, at one works in the United States, an open-hearth furnace of 185 tons capacity was recently installed, from which has been obtained over several weeks an average make of 1350 tons of ingots.

The increase in output has been greatly facilitated by the improvements which have been introduced in recent years in the auxiliary machinery, such as charging machines, cranes, and ingot strippers, now for the most part operated by electricity generated by waste gases, and the arrangements of many of the modern works are such that the same crane which strips the ingot places it whilst still hot in the reheating furnace, from which it can be delivered by another crane to the cogging-mill.

Rolling-Mills.—In the rolling-mill department the heating furnace now almost universally used is that arranged to heat the ingot in its vertical position, fired with either coal, producer gas, or waste gas from the blast-furnace or coke-ovens. The mills themselves have been greatly increased in capacity and power to deal more expeditiously with the larger production; and, for driving reversing-mills where steam is used, two-cylinder engines are being displaced by engines with three cylinders, either simple or compound, exhausting into a condenser, or into a turbo-blower or turbo-generator; the former, providing blast for the blast-furnaces; the latter, electric current for driving out-lying machinery.

Another form of drive for reversing-mills introduced at Teschen, Austria, in 1906, is by electric motor, on what is

known as the Ilgner system, which method has recently been adopted, both for cogging- and finishing-mills, by many important works on the Continent, chiefly in Germany, and by several in this country, numbering about thirty in all; whilst, I understand, about twenty more such equipments are at the present time being laid down.

Still, the modern reversing steam-engines, as above described for driving reversing-mills, have many ardent supporters, both in this country and on the Continent, on the ground of cheaper first cost and simplicity; and although electric motors are very largely taking the place of reciprocating steam-engines for driving continuously running mills both on the Continent, in the United States, in this country, and in Canada, it cannot yet be said that even for this purpose steam has been permanently displaced, for Messrs. James Dunlop & Co., who recently erected a new 3-high plate mill with rolls 28 inches diameter and 84 inches long, intending to drive it with an electric motor with current generated by steam from existing mills, after careful consideration abandoned the idea of the electric motor, and put down in place of it a mixed pressure turbine of 750 brake-horse-power, running at 2000 revolutions per minute, constructed to work either with exhaust steam from their other engines, or with live steam from their boilers, the supply of the latter being regulated automatically by a valve according to the duty required. The speed of the turbine is reduced by gear to run the rolls at 70 revolutions per minute, and the power is transmitted through a flywheel of about 100 tons weight. I understand that the mill was set to work at the end of 1910, and that it has in every respect proved satisfactory.¹

If the experimental surface combustion boiler described by Professor Bone at the Royal Institution on March 30 and April 6, 1911, for which an efficiency of 90 per cent. when fired with gas is claimed, can be developed into a commercial success, or if some other more economical steam generator than the present Lancashire or water-tube boiler with an efficiency of about 60 per cent. only can be devised, the

¹ For full description of this mill, see paper read by Mr. Carnegie, *Journal of the West of Scotland Iron and Steel Institute*, Nos. 5, 6, and 7, for 1911.

economy of steam turbines would, of course, be correspondingly increased.

For several years past the question that has exercised the minds of iron and steel works engineers, particularly on the Continent, perhaps more than any other, has been how to obtain most economically the maximum value from their coke-oven and blast-furnace gases, in order to save the coal used for producing power for their iron and steel works machinery and for their steel and heating furnaces, and with this object in view very large expenditures of capital have been incurred at all the important works. As an instance, I may mention that on a visit to one of the large German works consisting of coke-ovens, blast-furnaces, and steel works in 1897, I saw a range of boilers and an engine-house containing four pairs of powerful compound steam-blowing engines of the latest design and in splendid condition, and which at that time were operating their blast-furnaces. At a subsequent visit in 1906 I saw another large engine-house containing a magnificent plant of gas-blowing and power-engines providing blast and electric power for their blast-furnaces and steel works, and I was told that by the end of the year 20,000 horse-power would be generated in that house, and all from waste gases.

The boiler-plant and steam-engines were all out of action and kept as standbys. I have recently been informed that the consumption of coal in these works has decreased in quantity year by year, and it is expected that very shortly no coal will be required except for the locomotives.

This is but an isolated instance of what is taking place in many such works.

My friend, the late Mr. E. P. Martin, in his Presidential Address from this chair in 1897, referring to a visit he had recently paid to Mr. Greiner of the Société Cockerill, made use of these words: "Indeed, incredible as it may appear, if it were practicable to apply all the gas made at the blast-furnaces at Cockerills for raising power, they would be able to do away with all their boilers except those of the locomotives.

"If blast-furnace gas can be economically applied as the

motive power for driving large engines and for generating electric power. it would almost appear as if pig iron would soon become a bye-product, and the chief work of the iron-master of the future will be giving light and power to the country."

It is clear that Mr. Martin in 1897 regarded this subject as a most important one: but it is far more important to us to-day, having regard to the great increase in the cost of coal which has already taken place, and the certainty of a still further increase in the near future.

During the fifteen years that have passed since 1897, it has been demonstrated beyond all question that both coke-oven and blast-furnace gases can be economically applied, not only as the motive power for driving large engines and for generating electric power, but also as fuel for mixers, open-hearth furnaces, and heating furnaces: and I confidently believe the day is close at hand when in the best-managed large works, equipped with modern bye-product coke-ovens and blast-furnaces, the whole of the converting, heating, rolling and finishing operations will be carried out with no other fuel than their own surplus gases, and that if any of us fail to utilise our resources to the fullest extent, unless exceptionally situated, we may be left behind in the race.

In conclusion, I wish to express my heartiest thanks to our Secretary, Mr. Lloyd, for the statistics, and to many kind friends who fill the highest positions in some of the most important iron and steel undertakings in Belgium, Canada, France, Germany, and the United States, for valuable information as to the latest form of plant and methods of working in their respective countries.

His Grace the DUKE OF DEVONSHIRE moved that a cordial vote of thanks be passed to Mr. Cooper for his Address. This, having been seconded by Sir Hugh Bell and supported by Mr. W. Hawdon, was put to the meeting, and carried by acclamation. The text of these speeches will be found on pp. 23-26.

TABLE I.—*Output of Ingots in the World in 1880.*

	Great Britain.	U.S.A.	Germany.	France.	Russia.	Austria-Hungary.	Belgium.	Sweden.	
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Acid Bessemer	1,034,382	1,071,268	742,000	384,626		87,881	91,700		3,463,992
Basic		10,000	classified)	(not classified)		17,835	3,300		
Acid open-hearth		251,000	100,851			28,502	37,052		...
Basic		(not classified)	(not classified)				(not classified)		
Total in each Country	1,295,382	1,175,119	790,000	384,626	307,305	134,218	132,052	30,013	1,218,715

TABLE II.—*Output of Ingots in the World in 1890.*

	U.S.A.	Great Britain.	Germany.	Austria-Hungary.	France.	Russia.	Belgium.	Sweden.	Italy.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Acid Bessemer	3,611,694	1,612,730		149,660	144,801			92,247	
Basic	77,780	462,113	1,493,137	138,021	(not classified)			(not classified)	
Acid open-hearth	423,232	1,462,913		33,904	241,190			67,779	
Basic	90,000	101,287		178,015	(not classified)			(not classified)	
Other classes of steel			668,660						
Total in each Country	4,202,103	3,579,043	2,161,817	499,660	688,991	372,625	236,226	160,026	12,058,336

TABLE III.—*Output of Ingots in the World in 1900.*

	United States	Germany.	Great Britain	France.	Russia.	Austria-Hungary.	Belgium.	Sweden.	Spain	Italy.	Canada.	Other countries.
Acid Bessemer	Tons. 6,684,770	Tons. 223,064	Tons. 1,553,963	Tons. 949,283	Tons. 675,106	Tons. 68,646	Tons. 91,065	Tons. 91,586	Tons. 91,586	Tons. 91,586	Tons. 91,586	Tons. 91,586
Basic "		4,141,587	491,401	classified (not stated)	classified (not stated)	245,145		(not class-ified)	(not class-ified)	(not class-ified)		11,026,911
Acid open hearth	863,044	147,800	2,862,566	645,810	1,511,293	34,383	297,418	59,148				
Basic "	2,545,691	1,997,765	238,480	classified (not stated)	classified (not stated)	797,870		(not class-ified)				
Total in each country	10,082,065	6,540,945	4,904,088	1,560,164	2,486,399	144,664	654,897	298,483	170,731	115,887	23,454	100,000
												28,635,280

TABLE IV.—*Output of Ingots in the World in 1910.*

	U. S. A.	Germany	Great Britain	France.	Russia.	Austria-Hungary.	Belgium	Canada.	Italy.	Sweden	Spain.	Other countries.
Acid Bessemer	Tons. 9,412,672	Tons. 471,181	Tons. 1,484,300	Tons. 81,293	Tons. 463,744	Tons. 61,871	Tons. 1,275,500	Tons. 92,948	Tons. 97,700	Tons. 97,700	Tons. 97,700	Tons. 97,700
Basic "		8,040,044	441,012	2,346,600	classified (not stated)	classified (not stated)	297,500	classified (not stated)	(not class-ified)	(not class-ified)		23,634,469
Acid open hearth	1,200,180	164,390	6,433	1,148,548	2,566,842	1,303,829	129,660		20,700			
Basic "	1,629,349	1,575,394	58,635	classified (not stated)	classified (not stated)	classified (not stated)	classified (not stated)	5,4932	(not class-ified)	(not class-ified)		
Total in each country	25,917,251	13,311,667	6,669,988	3,664,741	4,239,646	2,133,244	1,892,460	100,160	655,000	16,500	919,500	31,000
												58,614,988

APPENDIX. *Finished Steel Products, 1910.*

	U.S.A.	Germany, 1909.	Great Britain.	Russia.	France.	Belgium.	Austria.	Italy.	Sweden.	Spain.	Canada.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Rail,	1,917,900	1,481,637	711,915	601,800	372,494	374,800	56,843	121,570			
O. H.	1,715,900		235,611								
Tires and axles,	241,957			122,400	38,682	31,800		1,771			
.			60,646								
Structural steel (girders, posts, &c.)	2,600,000			194,000	225,338	168,000	141,046		23,417		
O. H.			297,084								
Bessemer			28,937								
Shapes (sections),	1,825,000	1,319,614	530,034	1,010,000	308,386	137,830					
O. H.											
Bessemer			103,131		623,815	447,510	356,766		204,955		
Merchant bars	1,000,000		216,743								
O. H.											
Wire rods	1,400,000	909,563		60,470	126,500			7,700	137,465		
.					13,479			1,430			
Pipes,		165,426									
Plates and sheets	3,433,000	1,501,611	1,063,983	714,600	406,291	272,420	13,239		22,081		
.					41,449			37,320			
Templates	647,688	55,427									
Sheet bars and template bars			1,280,658								
.											
Forgings		413,149	112,071		43,447	2,510			13,630		16,463
Steel castings	921,686		66,492		34,375						
Totals	18,361,174	9,091,384	4,676,131	2,672,800	2,201,486	1,561,520	536,944	163,091	431,608	1909	16,463
Total finished products, (including other un-enumerated products)		1910								218,469	
		9,165,293	5,568,141	2,674,380	2,317,211			534,721			

IMPROVEMENTS IN ELECTRIC FURNACES AND THEIR APPLICATION IN THE MANUFACTURE OF STEEL.

BY HANS NATHUSIUS, DR. ING., HETTER OESBELLER.

THE various systems of electric furnace are so well known that it is unnecessary to describe these apparatus in detail. The author will therefore confine himself to a few general remarks with respect to the two most important systems—the induction furnace and the arc furnace—and to a detailed description of some recent improvements in the latter type with special reference to the combined arc-resistance furnace. The subject is one which cannot fail to be of special interest to metallurgists, since it appears in the light of recent experience that so far as the manufacture of steel by electric means is concerned the arc furnace is the furnace of the future.

THE INDUCTION FURNACE

The hearth of a simple induction furnace consists of an annular trough in which the ring of metal constitutes the secondary winding of an alternating current transformer. The source of heat is the electric current, which is induced in the metal by the alternating current in the primary circuit of the transformer.

The idea of generating the requisite heat in the very material which is to be melted and of introducing heat by induction of an electric current, thus avoiding the use of electrodes, seems highly promising, at least in theory. Unfortunately however, this system of furnace has shown many serious defects in practical working.

The above-mentioned advantages of the induction furnace can only be realised to the full when the furnace is used as a crucible, that is when small charges (1 to 2 tons in weight) are to undergo a pure and simple smelting process. As a

refining furnace the induction furnace is, for the following reasons, quite unsuitable.

The restricted space within the ring of molten metal is inconvenient for any metallurgical work such as rabbling the slag, the regular distribution of additions, sampling and controlling the process of charging. The molten metal is also exposed to a considerable cooling action, due to extensive cooling surfaces and the slag is apt to solidify in consequence.

The electrically induced heat can, of course, only be generated in the metal bath and not in the slag, which must therefore be heated indirectly by the underlying metal. Now it must be evident that it is against all principles of economy to heat the slag by means of the molten steel, the melting point of which is considerably lower than that of the slag. Consequently a much higher temperature has to be imparted to the bath than is necessary for the desired reactions.

The entire design of the induction furnace—which rather resembles an electrical apparatus than a metallurgical furnace—makes it impossible to work with large fluid masses of slag capable of producing reactions. The magnetic field of the transformer sets up lines of forces in the liquid steel and causes it to rotate at such a speed that the slag is thrown against the sides of the channel causing it to cool to a temperature below that at which it can react on the charge. Further, the speed of rotation causes the surface of the bath of metal to slope at an angle, so that only a small portion of the metal in the ring is covered with slag and the reactions are thus prevented. The lining of the furnace is also injuriously affected by the whirling of the particles against the sides of the furnace, due to the centrifugal force, an action which results in their being both mechanically and chemically attacked. Further, it is impossible to treat entirely cold charges in an induction furnace for unless a portion of the preceding charge is allowed to remain in the furnace the charge does not form a sufficiently perfect conductor for the secondary current. This is a particular disadvantage in cases where it is desired to produce steels of very different qualities.

A further disadvantage noticeable in some types of induc-

tion furnace for instance in the Rochling-Rodenhauser furnace, consists in having two heating channels which form the secondary coil of the furnace transformer, the latter being built into the furnace in such a manner that one leg of the transformer passes through a corresponding opening in the hearth.

From a purely metallurgical point of view it is desirable that delicate apparatus such as a transformer should not be attached to the furnace, which, when hard pushed may become red-hot, no. should a transformer be exposed to risk from splashes of molten metal, dust, and rough handling. The conditions are not greatly improved even when it is most carefully protected and cooled by an air current supplied by a somewhat expensive compressor plant. The air-cooling on the transformer side necessarily increases the heat losses. To this must be added the unpractical shape of the hearth due to the presence of the transformer which increases the length of time between heats due to the increased difficulty of making repairs. Lastly may be mentioned a most vital disadvantage of the induction furnace as compared with the arc furnace, namely, the cost of installation. Not only is the induction furnace more costly on account of its complicated construction and its character as an electric rather than a metallurgical apparatus but also because the current supply is considerably more expensive with this class of furnaces than with arc furnaces. All large induction furnaces with a capacity of more than 3 tons require motor generators or separate generators when the frequency of the generating plant is higher than 25 cycles per second. It is evident that the instalment of motor generators must add to the cost of the electric equipment and of the necessary foundations and buildings.

The electric generator for an induction furnace must, even with installations of medium size be designed for a frequency of 20 or less and for a power factor of between 0.6 to 0.7. The machine must therefore be in the ratio of $\frac{1}{2}$ or $\frac{1}{3}$ to, or 1.54 times larger than, an equaliser for a three-phase arc furnace. On account of the lower frequency the alternator will be considerably more expensive. The cost of an equaliser

for a three-phase arc furnace with an output of 750 K.V.A. at 750 revolutions and 50 cycles is only 43 per cent. of that of a generator for an induction furnace of the same capacity. The lower speed which is required to produce the low frequency of the generator for an induction furnace influences the price of the machine the more unfavourably the greater the output of the machine.

When the current is not supplied by a separate alternator at the generating station but by a motor-generator, the price is scarcely affected on account of having to instal a motor for the furnace transformer. In fact, if anything, it may be increased, as such a motor is more expensive if desired to run at lower speeds, and it must in any case be adjusted to the maximum permissible speed of the generator.

The first cost of an induction furnace installation may, of course, be reduced by making an extension to the central power station instead of transforming existing electric current. In that case, and if the prime movers are blast-furnace gas-driven engines, the electric generators for arc furnaces must also be designed for slow speed. The difference between the cost of an induction furnace and that of an arc furnace installation will then disappear, but only under the above-mentioned conditions. The induction furnace transformer always requires a separate set of conductors for low frequency, and also a regulating transformer or tension regulator unless a decentralisation is to be carried out, which is not always possible and generally introduces economical disadvantages. But even in the latter favourable case it will hardly be possible to equip an induction furnace at the same cost as an arc furnace, and certainly not at a less cost.

In addition to the greater cost of an induction furnace there is that of the plant for compressing the air for cooling. There also has besides to be added to the working expenses of an induction furnace the wages of two skilled attendants (for day and night shifts) for the special machines—be it a separate generator or a motor generator—and to carry out necessary repairs. In this respect the working expenses of an induction furnace are considerably higher than those of an arc furnace, which can be equipped with static oil transformers.

Further, rotary machines are likely to run hot, and the insulation of the moving coils is also more liable to puncture than that of the windings of a static transformer, built for the same voltage. An oil-transformer when once installed requires no attention beyond overhauling once a year. Generally speaking, the chance of a breakdown with a rotary furnace transformer is double that with a machine in the generating station. When the current is delivered direct from the generating plant—with or without a transformer—a breakdown is of less consequence, as the whole plant is kept in reserve, and, if necessary, another generator may be switched on to the furnace circuit. The time required to remedy any fault is therefore considerably shorter.

Finally, the working expenses with induction furnaces are much increased by the low efficiency which, including transformer losses, amounts to 72 to 82 per cent., whereas the efficiency of a corresponding arc furnace plant is 95 to 99 per cent.

That the above-mentioned defects of the induction furnace are admitted by those who have developed this system of electric furnace is clearly proved by the numerous new remedying devices which are always being patented. Rodenhauser has, for instance, introduced dams or lips in the channel-bottom in such a way as to allow only the layer of slag to rise above the upper edge of the lip. But the electric current is then obliged, at these points to pass through the thin and comparatively bad conducting layer of slag. Another inventor has placed bridges below the surface of the molten metal at the entrances of the narrow lateral channels of the hearth, with the object of retaining the slag so as to prevent it altogether from entering them. In another modification of this device the lower edges of these bridges are placed at the level of the surface of the bath, or just below it. By this contrivance the slag is prevented from entering the channels, and any which may have penetrated into them can easily be removed. In order to facilitate repairs spare interchangeable channels of compressed material with special coatings of alumina or silicates are kept in readiness for use. How far these and other improvements will really prove successful in

practice remains to be seen. It is nevertheless interesting to observe that the induction furnaces have lately been so much modified as to have lost their original character by making them approximate more and more to the arc-furnace type.

ARC FURNACES.

The construction and method of operation of arc furnaces are now well known, and a considerable number of them have withstood several years' practical test in every respect in numerous metallurgical works.

The principal advantage of the arc furnace consists in the ease with which the heating of the charge can be regulated to any desired temperature from above by electric arcs directed upon the slag which covers the metal bath. This method of heating, combined with other advantages of the electric furnace—such as a neutral atmosphere in the melting chamber and absolute purity of the heating agent—have enabled the production of reactions between the slag and the metal with respect both to oxidation and reduction which it was impossible to obtain with the resources previously available, and after a long experience in the working of electric furnaces the author has gained the conviction that absolutely new processes will in time be developed to supplement or perfect the present ones. This question will be referred to again later in the paper.

The readiness with which the arc furnace has been adopted is not only due to the above-mentioned advantages, but also to the fact that the electric conditions permit its construction to resemble closely that of the familiar converters and open-hearth furnaces. The usual type of arc furnace, such as the Héroult Girod, Keller, Stassano, and others, resemble the gas-fired furnaces in that the heat is applied to the charge at the surface, the gas-flame being replaced by an electric arc.

The author has for many years made a special study of arc furnaces and their working conditions, and he was soon obliged to acknowledge the great advantage of electric arc-heating. At the same time the idea occurred to him that it might be possible to combine the advantage of the arc furnace

(good heating of the slag) with the advantage of the induction furnace (heating in the charge itself) and thus to avoid the disadvantages of both systems. It became evident to him at once that the electric current offered the possibility of applying heat not only at the surface of the charge, but also at any part where an intense heat is required, such as in the charge itself or especially at the bottom of the furnace.

The transformation of the electric energy into heat in the substance of the material which is to be heated is neither a contact nor a transmission phenomenon but a thermodynamical frictionless heating, with 100 per cent. efficiency even at the highest temperatures. The only losses are those due to radiation and conduction. Hence in this process of heating the question is not—how much heat is imparted to the charge, but how much of the heat generated within the charge itself can be retained therein.

In the author's opinion it would be a mistake not to take this advantage into consideration. Besides, the natural method of heating consists in applying the heat not from above but from below. If this could be effected by some simple means then a most substantial advantage over other are furnaces would be gained, as the following thermo-technical considerations will show.

From the practical point of view the best method of heating is undoubtedly that which can be applied with the least possible loss, with the greatest possible regularity, and is so adjustable that the temperature of the furnace can be regulated at will between the required maximum and minimum.

These conditions are badly fulfilled in the simple are furnace. The losses through radiation and conduction are considerable, being greater than those in a gas-fired furnace, on account of the much higher temperature. The overheating of the surface is also greater for the same reason. On the other hand the heat losses due to the heating of quantities of air passing through the furnace are avoided in an electric furnace.

All these disadvantages are more or less eliminated in the induction furnace, which certainly best fulfils the required

conditions, and the question then arises as to why the arc furnace has made more rapid headway than its rival. The answer is simple: The problem of electric furnaces in technical metallurgy is less concerned with the thermo-technical side than with the metallurgical side, and the metallurgical requirements must always determine the choice of the system of furnace.

The processes which the steel metallurgist has to carry out in his furnace may be divided into three groups:

1. The melting process.
2. The refining process (oxidation by means of atmospheric air, or by iron ore).
3. Deoxidation or finishing process (alloying), degasifying, quietening.

The induction furnace is only to be recommended when it is a question of a melting process, and when its otherwise serious defects are not preventive. Notwithstanding its higher thermal efficiency, the working of an electric furnace is too costly to enable it to be used ordinarily for a melting down process. For purely economical reasons the less perfect but cheaper gas-fired furnace is preferable for this purpose. On the other hand, for a process of refining metal already melted, the arc furnace is particularly well adapted. To produce reactions which depend on the reciprocal action of the slag and the metal, it is requisite to have a very hot slag, and to be able to work with fluid masses of slag in large quantity. This cannot be done in the induction furnace, and the arc furnace alone lends itself to such operations. In finishing the charge, however, the steel has to be alloyed with other metals, and must remain quiescent for a period. For this purpose heating by an ordinary electric arc is less favourable. The reactions take place only within the bath; the slag has ceased to react, has become neutral, and serves now only as a protecting cover.

It is, however, impossible to make use of an arc furnace for one part of the process and an induction furnace for another. The difficulty can only be met by means of a combined arc and resistance furnace.

THE NATHUSIUS FURNACE.

In the author's furnace the charge is heated on the surface by several electric arcs, so distributed that the heating is effected as equally as possible. Heating by means of a single arc is absolutely impracticable, because the arc, though a very intensive, is a highly localised source of heat.

It has been said with some truth, that the arc in the electric furnace is a necessary evil. It is necessary for heating the slag, but its disadvantage is that its temperature must at least be that required to volatilise carbon ($3000^{\circ}\text{C}.$), since this is the essential condition of its existence.

Since the maximum desired temperature of the furnace is between 1900° and $2000^{\circ}\text{C}.$ it has been the author's endeavour to weaken the intensity of the arc as much as possible, and to reduce the unavoidable over-heating on the surface of the charge to a minimum. In order to effect this he transferred as much as possible of the energy required for a particular furnace to the bath, or rather to the bottom of the bath and the method of heating thus approximates to that of an induction furnace. By the aid of special means for the distribution of the current, it is possible to transfer a larger amount of energy to the arcs at the surface, or to the bottom electrodes as desired.

From the drawing in Plate I. it will be seen that the furnace is circular in form. The radiation and conduction losses are thus reduced to a minimum, and the doors allow of a convenient access to the hearth for the performance of the required metallurgical operations, such as drawing off the slag, sampling or repairs to the bottom. The furnace can be tilted by electric or hydraulic means. Small furnaces up to 6 tons capacity are tilted on trunnions resting on vertical supports (in the same manner as converters) and larger sized furnaces have rockers resting on rollers (like tilting open-hearth furnaces and mixers).

The characteristic of the furnace, as illustrated, is that it has three carbon electrodes above the surface of the charge which project through the roof into the furnace, and three or a multiple of three (3, 6, 9) bottom electrodes of mild steel

rammed in the hearth. The upper as well as the bottom electrodes are arranged in a regular triangle. No regulating devices or other electrical apparatus, such as transformers or motors, are attached to the furnace itself, but these are installed in a separate well-closed room behind the furnace as shown in Plate I.

The furnace is purely a metallurgical apparatus, and all operations may be performed without risk of burning a motor or transformer, or exposing a regulator to dust.

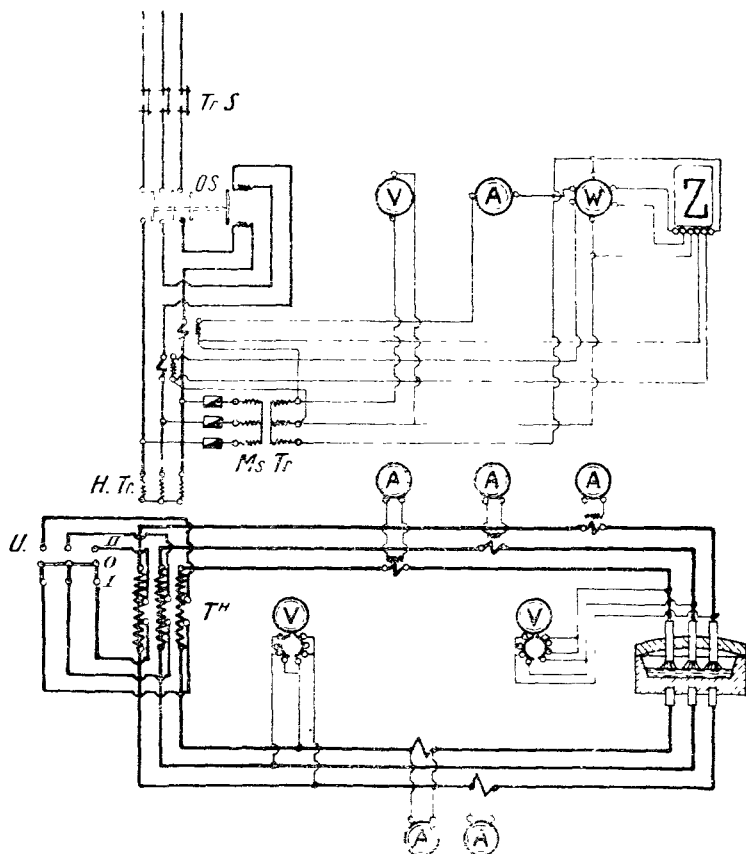
The carbon electrodes, which require continuous adjustment, are suspended by cables from overhead runways, and are either adjusted electrically or by means of handwheels from the switchboard. From the room where these are installed a good view of the furnace is possible. The independent suspension of the carbon electrodes comprises a number of advantages; first, it allows of tilting the furnace without having to tilt the electrodes. The breaking up of the electrodes is thus considerably reduced, as this generally takes place when the furnace is being tipped. When tilting the author's furnace the electrodes are simply drawn up; secondly, by suspending the electrodes from runways they can be readily drawn away to one side by means of a chain and quickly changed.

The lining of the furnace may be either basic or acid, and the roof is built of silica bricks. In a basic furnace the bottom and the side walls are lined with dolomite and tar rammed in the usual way. It is a good practice to lay a few courses of magnesite bricks where the roof and side walls meet. The required repairs to the side walls when renewing the roof can then be done very quickly. In the furnace under consideration, owing to the good distribution of the arcs and their reduced intensity, the local overheating of the surface is not so great. When it is required to renew the arch the side walls must also in most cases be repaired, as the roof and the sides bind together. Approximately, 100 heats may be obtained under one roof when only cold metal is charged, and nearly double that number when hot metal is charged. The fact of the current flowing through the bottom increases its durability considerably, for it is well known that a thorough

burning at high temperature is the best security for a high degree of refractoriness. As the bottom itself is heated to a high temperature it becomes burnt automatically. For the same reason repairs can easily be made, because the dry dolomite mass when thrown on the bottom is immediately burnt on. Any holes retaining puddles of liquid metal, which might prevent the burning of dolomite, are emptied to the last drop by tipping the furnace to a sufficiently steep angle. Slight repairs to the furnace can conveniently be done during the interval between two charges. Heavy repairs to the bottom are never required.

Coming now to the electric installation of the furnace: the current employed is a three-phase alternating current of any convenient frequency. This kind of current is the most convenient for metallurgical work and in its application economical as well as electrical and thermo-technical advantages are involved. A three-phase current of any frequency may be used. Even in the case of melting down cold charges it is not required to put down a motor-generator or a separate generator. The furnace can be connected direct to a step-down oil-transformer, which reduces the voltage of the mains to that of the furnace (110 volts). The saving in first cost, as well as in working expenses has already been commented on. Different systems of connection are employed according to the particular requirements of the furnace. The simplest and most useful connection when working with fluid charges is shown in Fig. 1. It will be seen that there are three surface carbon electrodes which are connected to the outer terminals of the secondary windings of the furnace transformer, and three bottom electrodes connected to the three inner terminals of the secondary coil. The three inner terminals of the transformer are obtained by separating the windings at the neutral point where the three secondary windings of an ordinary three-phase transformer are connected. By this means the neutral zone—if it is permissible for the sake of a clearer understanding thus to represent the electric conditions—is transferred to the bath itself and the current must gravitate from all points of supply towards this neutral zone. In other words the current, though supplied from a

single source only, is forced to flow not only between the upper and bottom electrodes, but also between any upper



Switch in O position = Zero point in the bath.

" I. " = Zero point in transformer with low tension in hearth electrodes.

" II. " = Zero point in transformer with high tension in hearth electrodes.

Z = Meter.

U = Switch.

A = Amperemeter.

V = Voltmeter.

W = Wattmeter.

T^H = Main transformer.

Tr. S. = Separating switch.

O. S. = Out switch.

Ms. Tr. = Measuring transformer.

H. Tr. = Boost transformer.

FIG. 1.—Wiring Diagram for Nathusius Furnace, arranged for working with high-tension alternating current, and transformer without neutral.

electrode and any bottom electrode. It is thus possible, with a single source of current, to heat the charge in all parts, pro-

vided that its resistance is sufficiently high, or that the current is strong enough to produce sufficient heat in the charge when the resistance is low.

Experts have expressed doubt as to whether any current flows through the bottom electrodes or even between the bottom electrodes of this furnace. In Fig. 3, in which (in two phases) the course of the current, flowing from the outer terminal (1) of the secondary winding of phase I, is indicated by arrows and numbers, it may clearly be seen that it is impossible for the current to return to the starting point if it passes only between the surface electrodes. Hence, with this connection, no closed circuit can be established through the surface electrodes only. Since the neutral point is disconnected and transferred to the bath, a circuit can only be established when an equalising current flows through the bottom electrodes as well as through the upper electrodes towards the neutral zone in the bath. According to the first law of Kirchhoff, the sum of the currents entering the surface electrodes must be exactly equal to the sum of the currents leaving the bottom electrodes. This proves without doubt, that there must be a passage of current between the bottom electrodes when current passes between the surface electrodes. Otherwise, the sum of the currents in the conductors of the surface electrodes could not be equal to that in the conductors of the bottom electrodes. It might be said that the currents are only flowing between the surface electrodes and the bottom electrodes, without also flowing between the individual surface electrodes and the individual bottom electrodes. This is, however, impossible, as the current must flow between two points, between which there is potential gradient and a conductive connection. Since there is a fall of potential between any two electrodes, and since the electrodes are all mutually in conductive connection through the metal bath, there must be a flow of electricity between the upper electrodes and also between the bottom electrodes. To obtain a clear conception of the electric conditions, it will be well to consider the various resistances and tensions in the furnace.

In a 5-ton Nathusius furnace the tensions are under normal conditions, as follows:—

Between the upper electrodes	110 volts.
„ „ lower electrodes	10 „
„ „ the upper and lower electrodes	61 „

The resistances are :—

A. Between the upper electrodes—

1. Resistances of two air spaces.
2. Resistance of two layers of slag.
3. Resistance of the bath or charge.
4. Contact resistance between slag and metal bath.

B. Resistance between the bottom electrodes—

I. Covered bottom electrodes :

1. Resistance between two layers of hearth material.
2. Resistance of the bath or charge.
3. Contact resistance between bottom electrode and hearth material.
4. Contact resistance between hearth material and bath.

II. Exposed bottom electrodes :

1. Resistance of the metal bath or charge.
2. Contact resistance between bottom electrode and metal bath.

C. Resistance between a surface electrode and a bottom electrode—

I. With covered electrodes :

1. Resistance of one air space.
2. Resistance of one layer of slag.
3. Resistance of the metal bath.
4. Resistance of the hearth material.
5. Contact resistance between slag and metal bath.
6. Contact resistance between metal bath, or charge, and hearth.
7. Contact resistance between hearth material and bottom electrode.

II. Exposed bottom electrodes—

1. Resistance of one air space.
2. Resistance of metal bath.
3. Contact resistance between slag and metal bath.
4. Contact resistance between metal bath and bottom electrode.

The tension between the upper electrodes and between the upper and the bottom electrodes is constant, whereas the tension between the bottom electrodes depends on the resistance between the bottom electrodes. It is now theoretically possible that in the case of covered bottom electrodes, and with a cold hearth at the beginning of a run the tension at the bottom may also reach 110 volts, under which condition no current could flow between the electrodes. Such a condition, however, does not occur in practice, because, as with an open-hearth furnace or a converter, a relined electric furnace must be heated before it can be started. The bottom will therefore soon become a good conductor; its resistance will diminish gradually as the furnace becomes warmer, and the tension will fall to 10 to 15 volts.

It is evident that the distribution of the current will be considerably influenced by any alteration of the air spaces, and of the resistance of the layer of slag or of the bottom material. If the charge consists of ore or of scrap iron with large air spaces, then the electric resistance of the charge is quite high enough to generate a sufficient heat in the charge, with the usual current of 3000 to 4000 amperes.

A better contact with the charge is obtained with exposed electrodes. These are made of mild steel, and, to prevent their melting it is necessary to cool the portions outside the furnace with water.

If the charge consists of fluid metal, such as mild steel then the heat in the bath may be increased by employing bottom electrodes covered with a layer of the hearth material, as shown in Plate I. This material will then act as a heating resistance, and the comparatively low resistance of the bath can be increased by taking advantage of contact resistance, hysteresis, eddies, or skin effect.

If this increase of resistance does not suffice to produce the necessary heat effect in the charge, then the current flowing between the bottom electrodes may be strengthened by inserting a booster transformer in the circuit of the electrodes, as shown in Fig. 2. By this means the heat produced by the bottom electrodes may be regulated from zero to any desired maximum, just as the arc-heat may be regulated by

lifting or lowering the carbon electrodes. By using the booster transformer in connection with a tension regulator

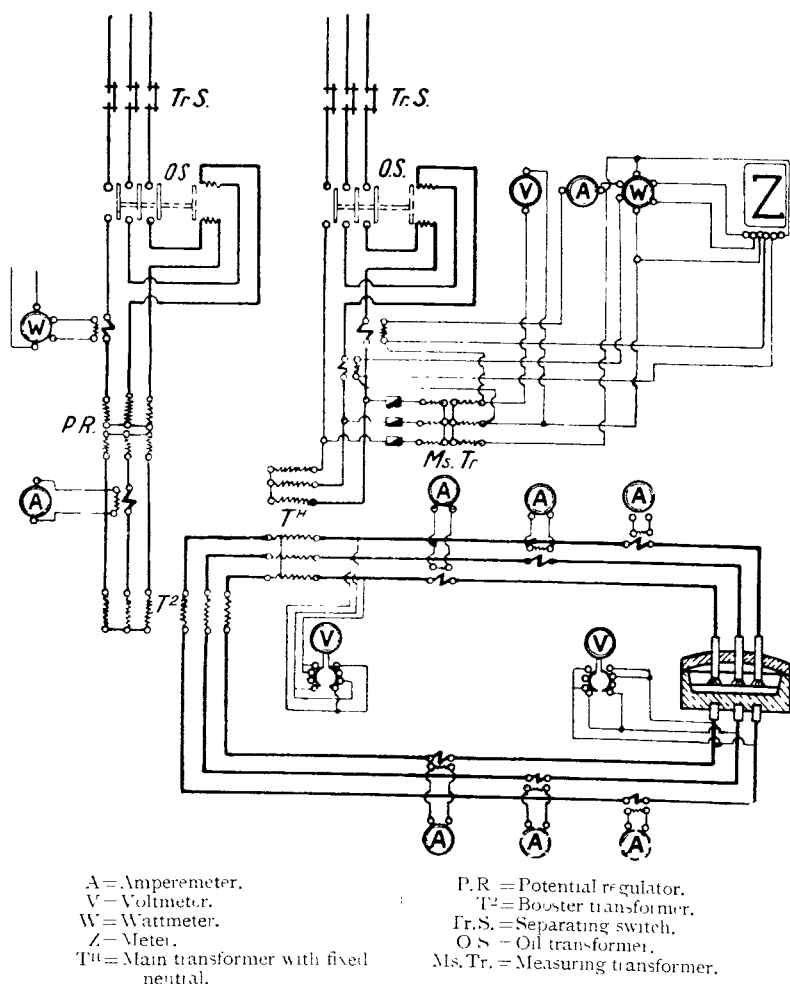


FIG. 2.—Wiring Diagram for Nathusius Furnace, with tension alternating current, main transformer with fixed neutral and potential regulator for variable hearth heating.

(see diagram of connections, Fig. 2), the energy delivered at the upper as well as at the lower electrodes can be regulated to any desired degree. The regulation is based on

changing the voltage, is independent of the actual resistance of the current, and is effected by the use of a double push-button without disturbing the working of the furnace and without switching the transformer out; it is also independent of the main transformer. The tension regulator is worked by a small auxiliary motor, supplied with energy by a small low-tension three-phase transformer. The circuit of the auxiliary motor is closed by manipulating one or the other push-button, and by means of a worm-gear the motor turns the tension regulator in either direction, whereby the tension of the transformers

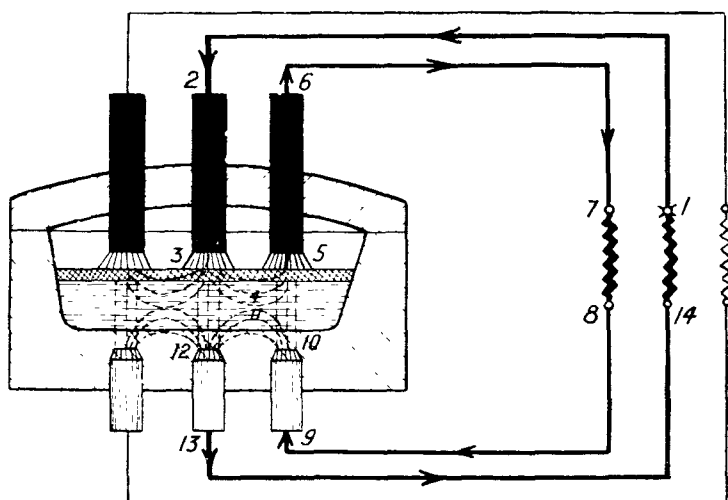


FIG. 3.

is either augmented or decreased. On the release of the push-button the motor and the tension regulator stop in the desired position. By means of a contact relay the regulation of the tension may be done automatically. The same operation may, of course, be carried out without the booster transformer. The main transformer must then have an adjustable neutral, whose position may be adjusted so as to increase the supply of energy to the arc-circuit or to the bottom-circuit, as required. A connection of this type is shown in Fig. 3.

The electric current can thus be compelled to flow through the bottom lining and the bath or charge, as well as through

the slag, and a comparatively large resistance is brought into the electric circuit. The resistance acts as an electric buffer by diminishing the unavoidable jumps in the arc-current, and thus enables the furnace to be worked either direct from the supply mains (if 110 volts is available), or on the circuit of an ordinary static transformer. The installation of an expensive motor-generator and complicated choking-coils are saved. The furnaces which have been in continuous work for many years at Friedenshütte bear out these statements. Both the 5-6-ton furnace and the 2-3-ton furnace are connected direct to the supply mains, and have never caused trouble at the generating station.

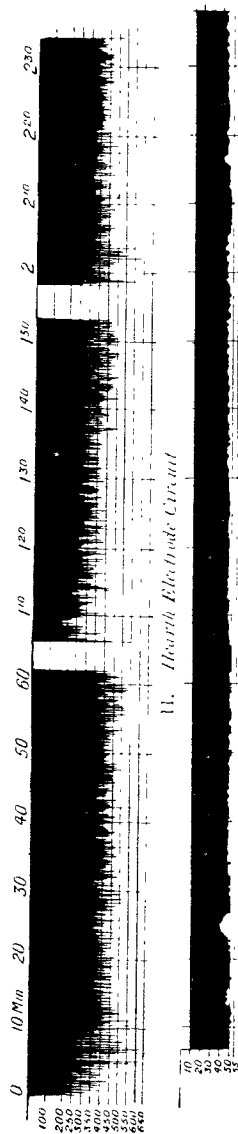
The accompanying load-curves also show that the favourable methods of connection adopted by the author eliminate the violent fluctuations in the arc-current. The curves have been determined by means of a registering wattmeter with unequally loaded phases, whereby the effects of the self-induction in both circuits (arc and bottom) are eliminated.

As may be seen from Fig. 4, in recording the measurements taken on the 5-6-ton furnace, the total working period of each heat is divided into two or three stages, each marked by adding new slag either once or twice. Small discrepancies in the curves are not caused by unsteadiness of the arc-current, but are due to fluctuations of the primary tension or to manipulations of the furnace.

It will be plainly observed that the state of the bath influences to a certain extent the fluctuations which occur shortly before slagging off, that is when the bath is particularly hot and boils while giving off gases; the fluctuations are also considerable after adding slag, because then the strongest reaction takes place.

The curves show that, at an average load of 350 kilowatts at the arc-electrodes an average load of 60 to 65 kilowatts is available at the bottom electrodes (Fig. 8). When the electrodes are bare the power in the bottom electrode circuit is reduced to 42 kilowatts (Figs 4 and 9). The curve in Fig. 5 is the secondary load curve of the arc-circuit of the 2-ton ferro-manganese furnace when melting down cold charges.

I. An Electrode Circuit.

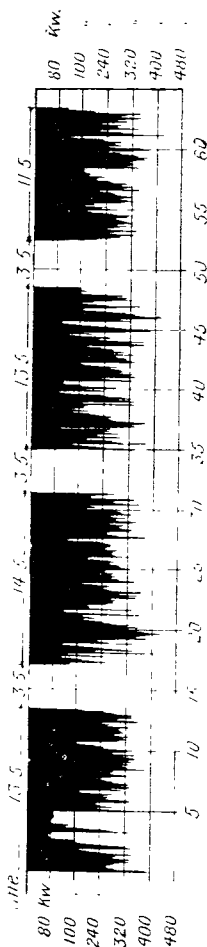


II. Hearth Electrode Circuit

Heat No. 1067, August 19, 1911.

Charge 5620 kilograms liquid basic steel
Yield 5650 kilograms material higher in silicon
Length of heat 2 hours 33 minutes
Total energy consumed (including transformer losses) . . . 1300 kilowatt-hours

Fig. 1.—Load Curves of a 5-ton Nathusius Furnace. (Exposed hearth electrodes. Curves taken on secondary circuit.)



The weekly average of 21 successive working weeks with this furnace was as follows:

Ferro-manganese treated 20,150 kilowatt-hours
Energy consumption including transformer and conductor losses . . . 21,700 kilowatt-hours
Energy consumption per ton of ferro-manganese melted . . . 841 kilowatt-hours

Fig. 5.—Load Curves of a Nathusius Furnace, specially arranged for melting ferro-manganese, with moderate bottom heating (Krammed hearth electrodes.)

Fig. 6 shows a load curve from the primary side of the transformer for the 5-6-ton electric steel furnace with fluid charge. The curve shows the fluctuations in the load, which is of importance to the generating station, and indicates that the furnace causes considerably less fluctuation of the current than a simple arc furnace, although it is only on the circuit of a simple transformer.

The curve in Fig. 7 clearly shows the difference in the fluctuations in the case of a simple arc furnace and those of a combined arc-resistance furnace. The Nathusius connection is applied in Diagram I., and that of a simple arc furnace in Diagram II.

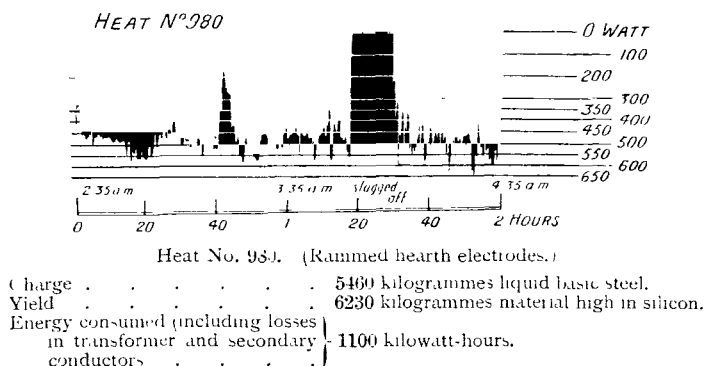


FIG. 6.—Load Curve of a 5-6-ton Nathusius Furnace.
(Primary circuit, with combined surface and bottom heating.)

The cause of these differences will be understood on considering the tension diagram. When the neutral point of the main transformer in the Nathusius connection is removed to the bath, the tension between the bottom electrodes is a function of the current flowing in the arc-circuit, *i.e.* certain tension fluctuations will be measurable at the bottom electrodes when great oscillations occur in the arc-circuit. Since the secondary phase-tension is at constant primary tension, the tension at the arc-electrodes must drop when the electrodes are short-circuited. Thus the oscillations due to short-circuiting of the arcs are damped, and this has a greater effect than the increase of the energy supplied through the bottom electrodes.

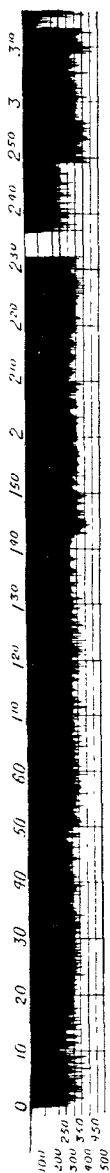
The putting in of a booster transformer does not alter these conditions, and it is therefore to be observed on the curves, Figs. 7 and 8, that each load peak in the arc-circuit corresponds to a load peak in the circuit of the bottom electrodes.

The lines of force traversing the molten steel bath produce a rotary magnetic field which causes a rotation of the material. In the author's furnace a moderate rotation of the bath is attained by leading the current through the large cross-section of the bath and in different directions. It is also obvious that by distributing the current in the depth of the bath as well as on the surface the rotary magnetic field is produced throughout the entire bath. In this way not only a very uniform heating of the bath is obtained, but also an extremely homogeneous product. This advantage is especially important in producing alloyed steels.

The question is now, how can an arc-resistance furnace be economically applied in metallurgy? To give a general answer is of course impossible, as it depends entirely on individual or local conditions as to how the electric furnace can be applied to the best advantage.

Taking the case of large blast-furnaces and steelworks where there is available blast-furnace gas, and therefore also comparatively cheap current and liquid steel either from a converter or an open-hearth furnace, and where the required grades of steel are not tool-steel, but ordinary steel such as hard material for rails, structural steel, projectiles, or soft material for tubes, plates, hydrogen flasks, &c. in large quantities, an electric furnace of the same capacity as the converters or the open-hearth furnaces is the most suitable, as undivided and partially refined charges can then be used. Whether this is possible depends upon whether there is a sufficiently good market for the grade of steel to be produced in the electric furnace. At Friedenshütte, however, a 5-6-ton furnace had to suffice, and this was in continuous work for more than two years in combination with basic steel works. The converters there have a capacity of 12 to 15 tons, of which 5 to 6 tons are charged into the electric furnace, and the remainder is cast into ingots. The results given in Table I. show this

Connections according to Diagram I.



Connections according to Diagram II.

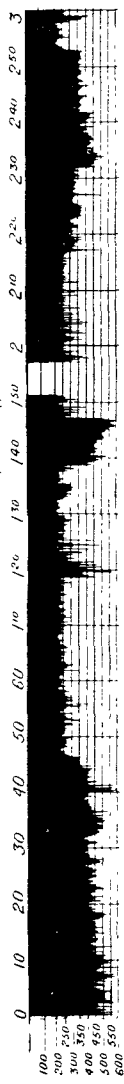


DIAGRAM I

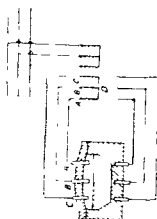


Heat No. 1025. July 21, 1911

Charge 5800 kilograms liquid basic steel,
 Yield 6000 kilograms low silicon material.

Energy consumed (including losses in transformers and secondary conductors) 1400 kilowatt-hours.
 Bare bath electrodes.

DIAGRAM II



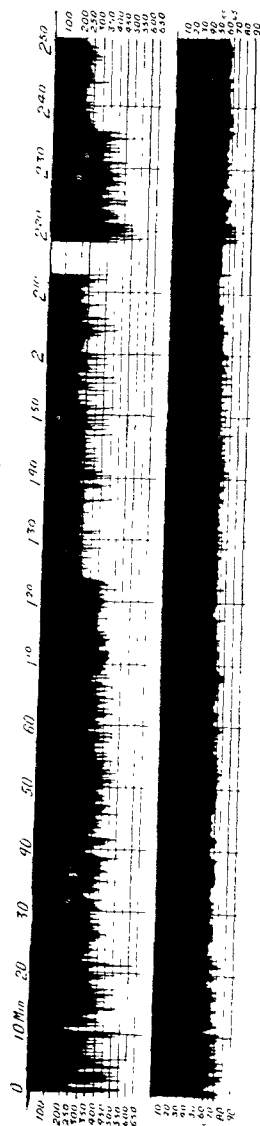
Heat No. 1056. August 15, 1911.

Charge 5570 kilograms liquid basic steel,
 Yield 5800 kilograms material higher in silicon

Energy consumed (including losses in transformers and secondary conductors) 1300 kilowatt-hours.
 Exposed bath electrodes.

Fig. 7.—Load Curves of a 5-6-ton Nathusius Furnace. (Are electrode circuit—secondary.)

I. *Pr. Fluct. C₂ at*



II. *Heath Fluct. C₂ at*

Heat No. 1248 October 31, 1911.

Charge	.	.	.	1860 kilograms liquid basic steel
Yield	.	.	.	5150 kilograms material higher in silicon
Length of heat	.	.	.	2 hour - 51 minutes.
Total energy consumed (including trans- formation losses)	.	.	.	1100 kilowatt-hours.

Fig. 8. Load curves of a 5 1/2-ton Nathans Furnace.

(Kamm lead electrodes. Curves taken on secondary circuit.)

disadvantage very clearly by the long duration of the heat and the high current consumption.

The partially refined initial charge of the electric furnace was of the following average composition:—

	Per Cent.
Carbon	0.367
Manganese	0.46
Phosphorus	0.065
Sulphur	0.07

After completion of the refining operation it had the following average composition:—

	Per Cent
Carbon	0.05
Manganese	0.10
Phosphorus	0.005
Sulphur	0.01

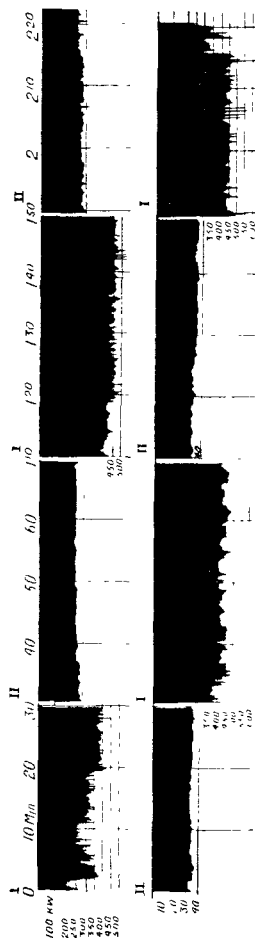
The method of working is, of course, unfavourable, because the deoxidising additions, such as manganese, must again be removed, which means waste of time and current.

One question, then, arises whether it would not be possible under certain circumstances to work the electric furnace economically in direct connection with the blast-furnace or mixer and thus dispense with the converter or the open-hearth furnace altogether.

In the present state of the electric furnace the author is of opinion that such a step would be premature.

In large metallurgical works cheap producer coal is generally available. In such cases gas-firing is always a cheaper heating agent than the electric current, even when the latter is generated by blast-furnace gas-engines. There is no object in performing operations in an electric furnace which can be done sufficiently well in a cheaper gas-fired furnace.

But even if coal is expensive and electric power very cheap, say at 0.07 of a penny per kilowatt hour the question must still be answered in the negative. In working up direct metal in an electric furnace by a process similar to the ore process in the open-hearth furnace, the refining would take too long a time, on account of the large quantities of ore and slag which would be required in the neutral atmosphere. The control of the large quantity of slag by heating from above with arcs would no doubt be a most difficult problem, and



Note.—The two curves were taken with two Watt meters in exact agreement with each other, which were simultaneously reversed.

Heat No. 1238, October 27, 1911.

Charge	.	.	.	.	5330 kilograms liquid basic steel.
Yield	.	.	.	.	5630 kilograms material higher in silicon
Length of heat	.	.	.	.	2 hours 21 minutes.
Total energy consumed (including trans-	.	.	.	.	} 1200 kilowatt-hours.
former losses)	.	.	.	.

Fig. 9. — Load Curves of a 6-ton Nathans's Furnace (Exposed electrodes in the hearth. Curves taken on secondary circuit.)

the refining would be indefinitely prolonged. Even with the cheapest possible power supply the cost of transformation would unquestionably be higher than that of heating an ordinary tilting open-hearth furnace.

The author is of opinion that the conversion of pig iron by electric means may economically be performed in a heated mixer or tilting open-hearth furnace. When an open-hearth furnace is charged with hot iron either direct from the blast-furnace or from a hot mixer it is a well-known disadvantage that the whole bath must be kept unnecessarily hot for a long time after adding the cold slag additions before an energetic reaction can take place between the metal and the still unfused slag.

The slag additions might, however, with advantage be melted in a separate furnace, and for this purpose the electric furnace, and particularly the combined arc-resistance furnace, is better suited than any other because of the high temperature attainable and the high resistance of the charge. The fluid slag of the proper composition can then be charged direct on to the metal bath. A violent reaction and disturbance will then take place in the bath, and the refining will be completed in a very short time. In large steelworks, with a row of open-hearth furnaces at work and where the demand for fluid slag is continuous, the electric furnace may be arranged as a kind of slag-mixer which can always deliver slag capable of reaction. This method might perhaps be usefully applied in the Talbot, Bertrand-Thiel, or Hoersch processes.

In any case, the time of the refining process would be considerably shortened, while it is evident that the two molten masses can react more rapidly on each other. The reaction is also certain to be more complete than when the slag is charged cold. Under these conditions it may become possible to convert direct metal into mild steel in an electric furnace, assuming the electric energy is generated by means of blast-furnace gas.

The same method may also be used with advantage in combination with a heated mixer and a tilting open-hearth furnace. A third furnace—an arc-resistance furnace—may be added with advantage. Such a combination of furnaces is shown in Fig. 10. It will be seen that there are three

furnaces. Furnace C represents the hot mixer, B the tipping open-hearth furnace, and A the arc-resistance furnace.

The three furnaces are intended to work together in such a manner that furnace A contains steel (refined metal III.) which has undergone a preliminary refining in the two furnaces C and B. For the removal of the remainder of the impurities the hearth is charged with a highly oxidic slag (1).

Furnace B contains pig iron (medium metal II.) which has already been partially refined in a mixer (furnace C). The further refining is effected by slag 2, now lower in oxygen, from furnace A.

When the reaction is finished in furnace B the metal (II.), the refinement of which is now fairly advanced, is charged into furnace A, while the pig iron bath I. is treated in furnace C with slag 3, now comparatively low in oxygen. The slag in furnace C is then poured off, and is a most valuable one if the pig iron used is phosphoric. At the finish the slag consists chiefly of lime, silicic acid and phosphoric acid.

This method possesses many advantages. First the phosphorus contained in the pig iron and valuable in the slag, is not lost. Secondly all the iron in the slag is reduced, and the yield can thus be increased. Thirdly, very little or no worthless slag need be produced, which saves the expense of transport to the waste heap. Lastly, the refining of the metal can be carried practically to perfection.

For the melting down of ferro-alloys electric furnaces may also prove highly useful in large iron and steelworks. For this purpose the arc-resistance furnace has special advantages. In order to melt down the expensive alloys quickly and without waste or evaporation losses, the heating must be as uniform as possible—conditions which can be realised fully with an arc-resistance furnace. The West German Thomasphosphate Works have a method for melting down and working these ferro-alloys in which the material, such as ferro-manganese, is to some extent overheated, is kept molten for some time in a mixer under the one slag, and is overheated somewhat without loss of manganese through burning or evaporation.

This process has been used for more than a year at Friedenshütte in Upper Silesia using an arc-resistance

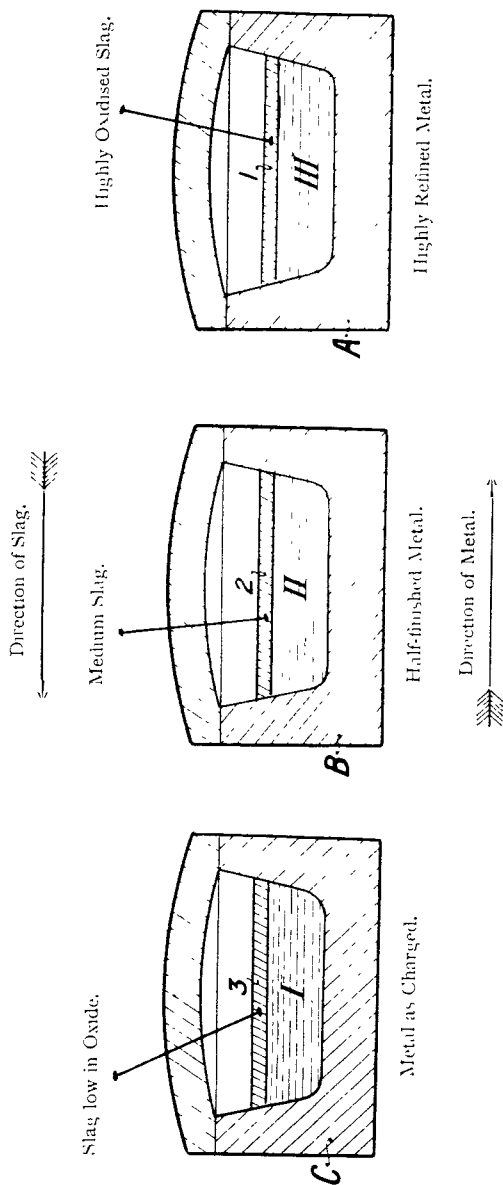


FIG. 10.

furnace of 2 to 3 tons. The furnace is in continuous operation, and is employed to melt down ferro-manganese for use in the basic Bessemer converter. The gain obtained by this process amounts generally to 0·35 shilling net per ton of steel, and has at times risen to over 0·4 shilling. It is based on the saving of ferro-manganese, which amounts to about 30 per cent. of the former consumption when using cold ferro-manganese. The saving is effected by the taking up of all the molten ferro-manganese into the bath and the losses in the slag are eliminated. The molten ferro-manganese reacts much more vigorously, and a smaller quantity is therefore required to produce the same reducing effect as a larger quantity of cold ferro-manganese. Lastly, ferro-manganese which has crumbled to powder through storage for a long time may be used without disadvantage, whereas formerly it was considered valueless.

In Table IV. it is stated that the cost of the former method of heating the ferro-manganese in a reverberatory furnace was 4s. 2d. per ton, and that that of the present melting-down process in an electric furnace is 19s. 1d. Table V. shows that by saving 30 per cent. on the former annual consumption of 3300 tons of ferro-manganese, the gross saving amounts to £8208, 15s. This is a considerable saving in less than one year, due to the introduction of the electric furnace.

But even if the costs of current, ferro-manganese and other items were such that there would be no net saving, it would nevertheless be of advantage to erect an electric furnace for the process. By the use of molten and somewhat overheated ferro-manganese important improvements are obtained in the quality of steel, and the working is facilitated.

The speed of diffusion with molten and slightly overheated ferro-manganese is of course much greater than that of cold ferro-manganese, the reason being that the reactive capacity of the molten ferro-manganese is much greater, and the de-oxidation of the steel is consequently much more thorough. This is proved by the fact that overblown charges can easily be remedied with molten ferro-manganese. Further, material containing 0·25 to 0·3 per cent. of manganese can be easily rolled without cracking when the charge has been reduced by

molten ferro-manganese. while the material from similar charges reduced with cold ferro-manganese containing up to 0.3 to 0.4 per cent. have broken in the rolling-mill.

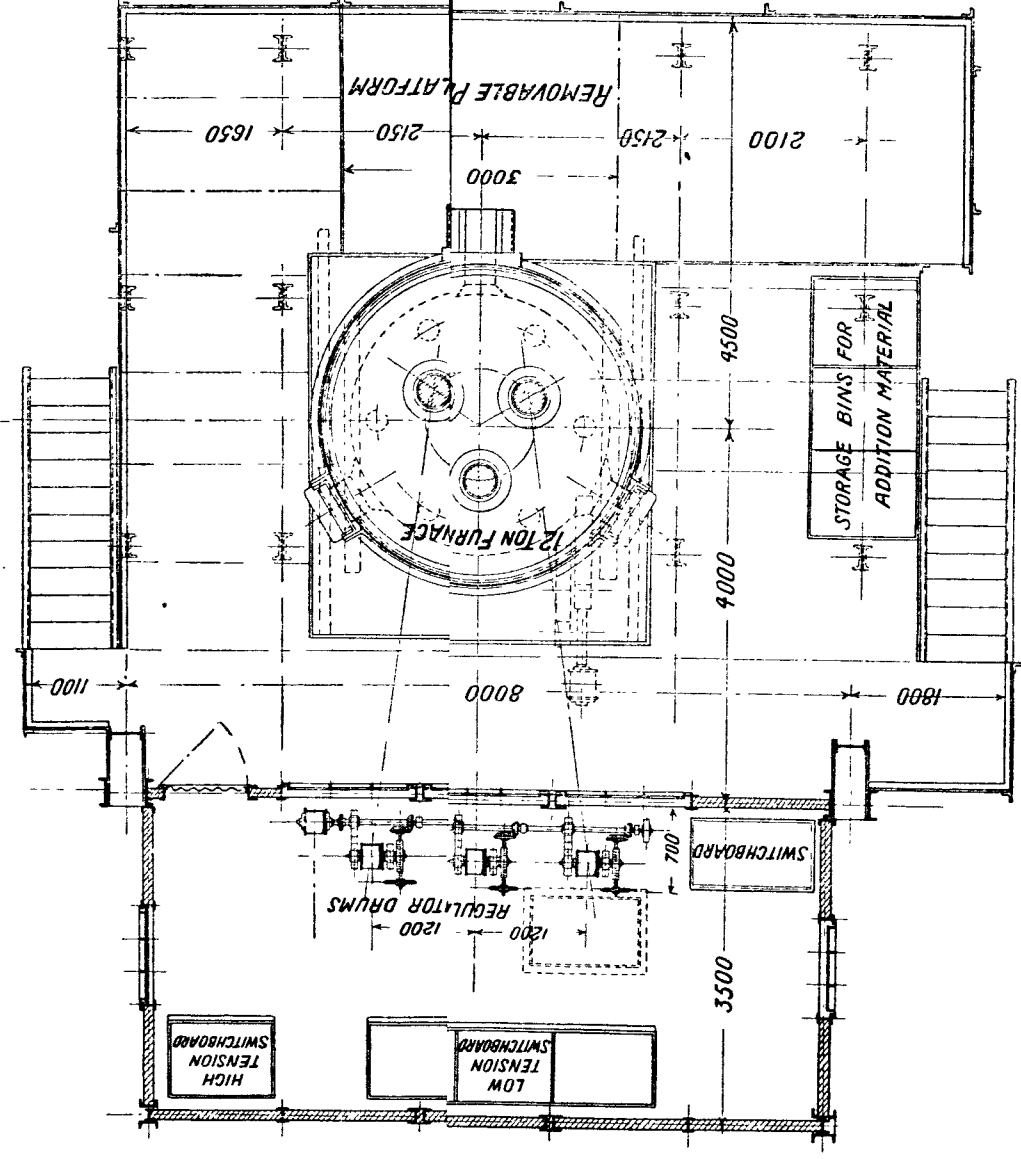
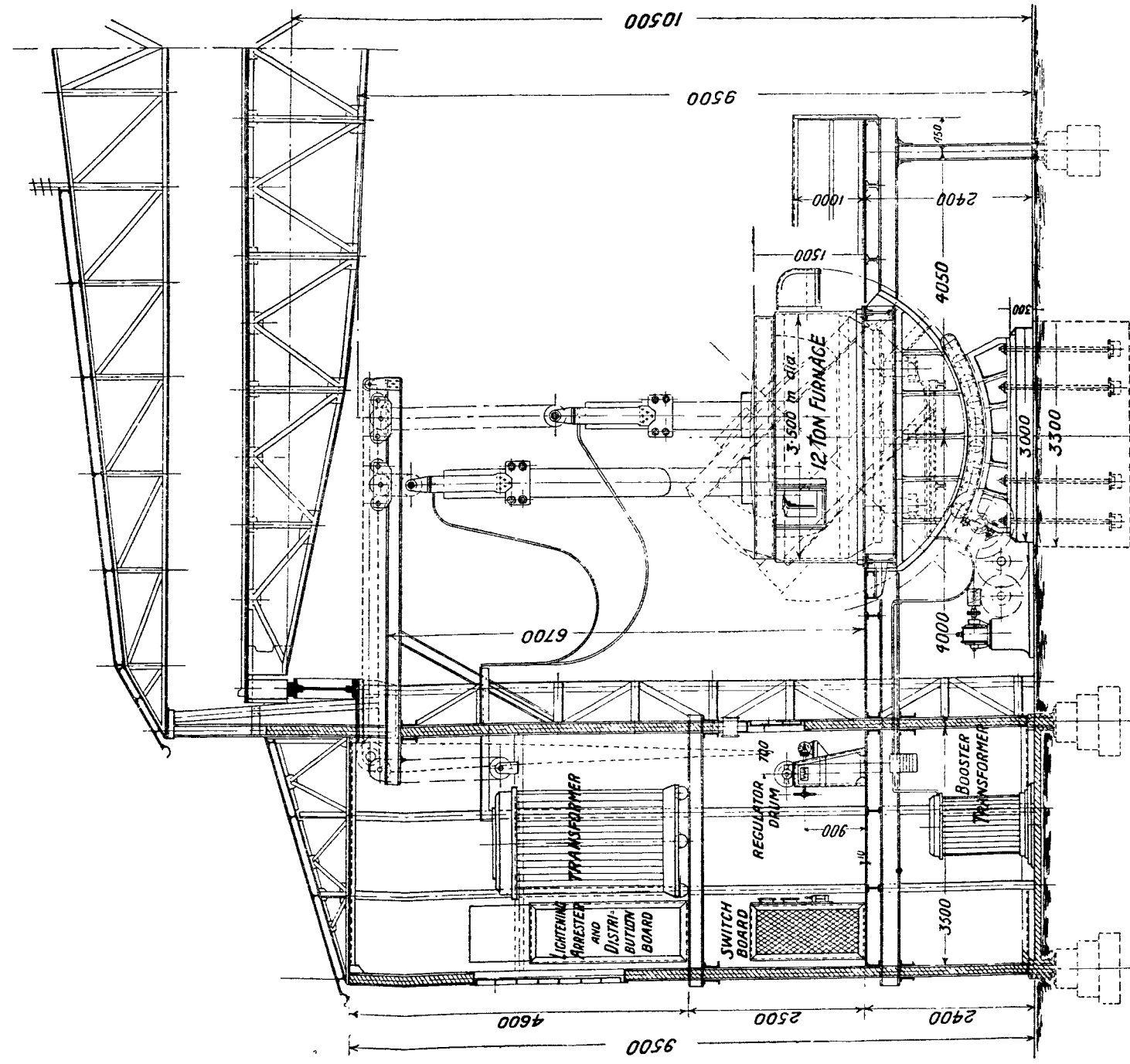
Further—what is very important in the manufacture of rails—the portion of the molten ferro-manganese which is required to alloy with the steel distributes itself much more regularly in the iron, as the alloying capacity of the molten ferro-manganese is much greater than that of the cold ferro-manganese. The segregation of the manganese, which otherwise easily occurs, is thus eliminated. Also the reducing back of phosphorus from the slag into the bath when cold ferro-manganese is used, is avoided. The molten ferro-manganese does not come into contact at all with the slag of the steel charge, because it is poured straight into the clean stream of metal while the converter is being poured. The result is that the desired chemical composition of the final product is obtained with much greater certainty, and spoiled charges are avoided.

Since the adoption of the molten ferro-manganese process at Friedenshutte, the analysis of the converter charges have shown a much greater uniformity.

The foregoing clearly shows that the melting down of ferro-manganese in an electric furnace, and its application all at once in the liquid state for the deoxidation of basic steel charges, is an important metallurgical improvement on the Bessemer process. The technical progress of the latter method has of late years been more in a purely constructive direction, such as an improved arrangement of converters or transport of materials. In the metallurgical sense, a certain stagnation seems to have set in which, rightly or wrongly, has brought the old process into discredit. The author hopes that this new method of reduction will serve the purpose of restoring its former credit.

Among basic steel works in Germany which have adopted the new process may be mentioned the Friedenshutte Works and the Hasper Works.

It is obvious that the same process may be applied to the basic open-hearth furnace or the Talbot process, when a large number of these furnaces are working continuously. The saving in ferro-manganese will probably be as great in these



ELEVATION AND PLAN OF 12-TON NATHUSIUS FURNACE.

cases, and an improvement in the quality of steel would result. The new method would also prove of great advantage in cases where reduction must take place in the ladle, as in the Talbot process.

Instead of ferro-manganese alone, one might also melt down mixtures of ferro-manganese and ferro-silicon or aluminium, according to requirements. The result is always the same, namely, improved qualities and saving of expensive flux.

The author believes that steel alloys of tungsten, chromium, molybdenum, &c., as used for ordnance and armour plates, may with advantage be melted down in a small electric furnace and charged in a molten condition. This method ought also to be useful in the production of high silicon steels and high manganese steels.

In conclusion, the author must not omit to refer to the following applications of the electric furnace:—

There is a great deal of waste at large tool-steel works of valuable steel alloys, such as turnings of nickel chromium steels, tungsten steels, or high silicon steels. This waste cannot be melted down with advantage in an open-hearth furnace or in a crucible furnace. The reducing slag and the oxygen of the open-hearth furnace gases would cause a great waste of valuable material. In a crucible furnace the material may absorb carbon from the crucible, and being too open, it is not suitable for charging crucibles. The crucible furnace is also too expensive.

In the electric furnace the material may be melted down under a neutral slag and in a neutral atmosphere practically without any waste and without changing the chemical composition of the charge. The electric furnace is also more suitable for open material on account of the easy access and its greater capacity compared with the crucible.

There is hardly any metallurgist who will deny that the electric furnace is more perfect than any other furnace of the present day. If nevertheless the results in many cases have not been so good as might have been expected in the hands of an experienced metallurgist then the reason is—as has often been the case in the past—that the development has advanced at a greater speed than the requirements

TABLE I.

Heat No.	Length of Time	Charge.	End Analysis.				Kilowatt-hours consumed per Ton.	Yield in Kilogrammes
			P.	Mn.	C.	S.		
	hr. min.							
186	3 0	Liquid	0.008	0.15	0.05	0.01	242	5600
189	3 0	"	0.01	0.14	0.05	0.01	237	5720
343	2 10	"	0.003	0.16	0.07	0.014	236	6100
388	3 40	"	0.002	0.11	0.058	0.018	265	5750
409	3 10	"	0.005	0.08	0.058	0.01	282	5410
485	2 45	"	0.003	0.115	0.06	0.017	255	5390
541	3 0	"	0.01	0.22	0.05	0.01	218	5780
556	3 30	"	0.002	0.093	0.05	0.008	265	5450
559	3 10	"	0.003	0.10	0.05	0.01	225	5630
562	3 30	"	Sp.	0.01	0.05	0.01	229	5520
564	3 20	"	0.003	0.13	0.05	0.01	225	5590
567	3 20	"	0.001	0.13	0.05	0.01	244	5370
613	2 45	"	0.003	0.07	0.05	0.01	248	5460
627	2 10	"	0.004	0.09	0.06	0.01	232	5440
628	2 40	"	0.005	0.09	0.05	0.01	229	5100
630	3 0	"	0.004	0.10	0.05	0.01	170	5890
633	3 15	"	0.003	0.59	0.13	0.01	226	5400
636	3 10	"	0.01	0.13	0.06	0.01	176	5630
638	2 50	"	0.003	0.12	0.06	0.01	172	5750
639	2 45	"	0.005	0.09	0.05	0.01	189	5700
641	2 40	"	0.015	0.14	0.06	0.01	190	5680
647	2 30	"	0.003	0.11	0.05	0.01	180	5470
648	2 30	"	0.05	0.15	0.05	0.01	173	5210
848	2 20	"	0.004	0.54	0.07	0.015	154	5830
927	2 25	"		0.78	0.05	..	155	5800
918	2 30	"		0.59	0.05	..	154	5850
928	2 0	"		0.20	0.05	..	160	5600
1529	4 30	Solid		0.24	0.09	..	650	5540
1526	6 0	"		0.22	0.095	..	685	5400
1517	5 30	"		0.25	0.157	..	680	5450
1418	5 40	"		0.18	0.16	..	610	5750
1458	5 30	"		0.15	0.085	..	660	5750
1543	6 20	"		0.165	0.16	..	680	5600
1520	6 0	"		0.25	0.126	..	666	5700
1477	6 50	"		0.17	0.10	..	693	5650
1472	5 50	"		0.20	0.068	..	680	5300
1420	6 15	"		0.18	0.085	..	695	5600
559	7 55	"	0.009	0.27	0.86	Sp.	510	4900
468	7 55	"	0.019	0.40	1.09	Sp.	747	4880
470	7 35	"	0.009	0.35	0.59	Sp.	478	5580

TABLE II.

Heat No.	Length of Time.	P.	End Analysis.			N.	C.	Kg. per Min. ²	Tensile Stress.			Limit of Elasticity, Kg. per Min. ²	Kilowatt-hours consumed, per Ton.	Yield in Kilo-grammes.
			Mn.	C.	S.				Elongation per Cent.	Contraction per Cent.				
	hrs. min.													
	3 0	Liquid	0.014	0.48	0.006	0.90	0.45	84.0	10.5	40.32		275	5080	
	3 30	"	0.004	0.44	0.008	1.39	0.38					290	5880	
974	4 0	"	0.002	0.83	0.014							210	5750	
1168	3 40	"	Sp.	0.03	0.015	0.005		33.8	32.0			260	5400	
1170	3 30	"	0.015	0.66	0.015			96.5	10.5			300	5150	
1161	3 40	"	0.01	0.85	0.02			100.0	12.0	40.75		275	5000	
1127	4 0	"	0.005	0.76	0.01	22.37		112.2	13.5	51.2		275	5450	
1546	3 40	"	0.009	0.70	0.014	1.61		50.4	18.5	51.2	37.1	215	5550	
1528	3 0	"	0.006	0.69	0.017	1.63		52.0	19.0	49.9	36.2	310	5500	
463	8 35	Solid	0.017	0.40	0.022	3.93	0.92					621	4830	
467	9 40	"	0.017	0.44	0.036	1.07	1.61					753	4690	

TABLE III.—*Cost of Conversion of 1 Ton of Liquid Electric Steel in the 5-6-ton Nathusius Furnace.*

WITH LIQUID CHARGE		Shillings.
<i>Additions:—</i>		
Ores (at 29.15s. per ton), 25 kilogrammes		0.72
Lime (at 12s. per ton), 30 kilogrammes		0.36
Sand (at 2s. per ton), 3 kilogrammes		0.03
Fluorspar (at 26.20s. per ton), 4 kilogrammes		0.11
Petroleum coke (at 38s. per ton)		0.12
<i>Deoxidising Agents:—</i>		
Ferro-manganese (60 per cent. at 158s. per ton), 6 kilogrammes		0.95
Ferro-silicon (75 per cent. at 310s. per ton), 1 kilogramme		0.31
Aluminium (at £67 per ton), 0.5 kilogrammes		0.67
<i>Refractory:—</i>		
Roof (at 12 10s. per ton), 100 heats per ton		0.50
Crushed magnesite (at 50s. per ton), 4 kilogrammes		0.20
Crushed fireclay (at 15s. per ton), 4 kilogrammes		0.06
Basic material (at 34s. per ton), 15 kilogrammes		0.51
Crushed fire-brick (at 17.50s. per ton), 4 kilogrammes		0.06
<i>Electrodes:—</i>		
(At £14, 10s. per ton), 5.7 kilogrammes		1.65
Holder (at 1.50s. per ton)		0.09
<i>Wages:—</i>		
Six hands		1.80
<i>Current:—</i>		
250 kilowatt-hours at 0.03s.		7.50
<i>Depreciation and Interest:—</i>		
10 per cent., and 5 per cent., on capital outlay of £5000, patent royalties and management charges not included		1.70
		<hr/> 17.33
WITH SOLID CHARGE.		
Lime (42.8 kilogrammes at 1.20s. per 100 kilogrammes)		0.51
Sand (5 kilogrammes at 0.20s. per 100 kilogrammes)		0.02
Dolomite (52.5 kilogrammes at 3.40s. per 100 kilogrammes)		1.78
Fluorspar (6.4 kilogrammes at 2.62s. per 100 kilogrammes)		0.17
Refractory material		3.39
Coke (2.3 kilogrammes at 3.80s. per 100 kilogrammes)		0.09
Coal for heating ladle (36.6 kilogrammes at 2.03s. per 100 kilogrammes)		0.77
Electrodes (13.3 kilogrammes at 30s. per 100 kilogrammes)		4.00
Current (790 kilowatt-hours at 0.03s.)		23.70
Wages		8.54
Repairs		3.70
Various materials		0.48
Depreciation and interest on £5000 (15 per cent.), patent royalties and management charges not included		3.30
		<hr/> 50.45

Estimate of profit assuming that a saving of not more than 20 per cent. is made by liquid admixing, that is, that with liquid ferro-manganese, the annual consumption is 2640 tons.

	Tons.
Former consumption of solid ferro-manganese per annum	3300
Present	2640
Annual saving in ferro-manganese	660
	<hr/>
Representing a gross value of 660 \times £8, 5s. 10d.	£ 5472 10 0
From which deduct—	£ s. d.
Present cost of melting, 2640 \times 19s. 1½d.	2524 10 0
Less—Former cost of heating, 3300 \times 4s. 2½d.	694 7 6
	<hr/>
Annual net saving	1830 2 6
	<hr/>
	3642 7 6

DISCUSSION.

Mr. A. WINDSOR RICHARDS (London) said that the paper would be read by every metallurgist if only to find out if any substantial reduction in working costs with the electric furnace had been brought about. That was the important point in electric furnace working, but after consideration of the question it appeared to him that except in those countries where there were large deposits of good iron ore and cheap power the electric furnace was not likely to make very much progress. The author admitted that the question of cost was a serious one, and from that point of view Mr. Richards wished to criticise the processes suggested by the author. Reference was made to molten oxide, and certainly no one who had worked the molten basic open-hearth process could doubt that such oxide would hasten the process very much. It was suggested that it should be melted in an electric arc furnace, and the fluid oxide poured into a second furnace containing the molten metal, and that such a method might be usefully applied in the Talbot, Bertrand-Thiel, or Hoesch processes. There was no doubt that such a method would increase the speed of working very much; but that would be achieved at considerably greater cost, and it must at the same time be borne in mind that the resultant product would not be electric steel at all, but would still be Talbot, Bertrand-Thiel, or Hoesch steel. Dr. Nathusius went on to state the method might be employed with two electric furnaces, one for melting oxide and one for refining; but several considerations arose in connection with the proposal to employ two furnaces for making one heat, and the expense would make it impossible. Then there was the suggestion of employing three furnaces, the three being intended to work together, and the third furnace containing steel which had undergone a preliminary refining in the two other furnaces, the slag being brought back from one furnace to another. The author suggested that the method possessed many advantages, but Mr. Richards could only describe it as a maze of operations. Perhaps the most important part of the paper was where the author dealt with the melting down of ferro-manganese in arc furnaces. That seemed to be an important and useful development which might commend itself to steelworkers. Reference was made to the fact that there was a distinct gain by that process, based on the saving of ferro-manganese, and indeed the author stated that less manganese was used, a statement with which Mr. Richards agreed. The process would be rendered more efficacious and the resultant steel would be improved.

Mr. E. C. IBBOTSON (Sheffield) assumed that the author's experience had been entirely with arc furnaces. At the present time the original Kjellin simple induction furnace in Sweden was still at work, although the owners had tried several other types of electric furnaces, producing a fair quality tool steel. With regard to highest quality

of carbon tool steel, with, for instance, 1·30 per cent. of carbon, it remained to be proved whether any type of arc furnace could produce such steel. He (Mr. Ibbotson) was not a basic steel man, although he had seen a good deal of the "Rochling-Rodenhauser" induction refining furnace, which was working commercially. Four at Luxemburg were making excellent steel castings. As to the comparative consumption of current in induction and arc furnaces, for an equal amount of melting or refining the induction furnace was quite as low as the arc furnace. There had been a good deal of theoretical exaggeration about the pinch effect and the non-heating of the slags in induction furnaces. Unfortunately, until recently the induction furnace in Great Britain had not had a fair chance. At Sheffield the first induction furnace put down was started up with an old altered generator which only gave about half the power required. The next two induction furnaces were put down by an electrician: they never had a proper lining, and no results were obtained. At the present time there was an induction furnace in Sheffield in which about 300 tons of steel had been made on trial; but that furnace up till recently had been hampered by so-called improvements.

Mr. E. H. SANITER, Bessemer Medallist, said that through the kindness of Dr. Nathusius he had, a year ago, seen the furnace working. It appeared to be working quite satisfactorily, but whether the rather complicated electrical arrangements realised the heating of the bottom as claimed, he was not able to say. At that time the electrodes were buried in the bottom. He now noticed that both buried and exposed electrodes were mentioned in the paper; he would like to ask which sort were now used in the furnace. He would be rather inclined to think that the use of buried electrodes when melting cold charges would damage the bottom, and that view seemed to be confirmed by the consumption of 52·5 kilogrammes of dolomite per ton of steel given in the cost sheet. He agreed with Mr. Richards that it would be a difficult process to transfer slag from one furnace to another. The melting of ferro-manganese might be economical for the basic Bessemer process, where the waste of manganese was very high, but the reverse for the basic open-hearth, where the waste was very low.

Mr. E. KILBURN SCOTT (London) thought that the author had sufficiently condemned the induction furnace to abrogate the need for any further remarks on that head. He approached the subject from the standpoint of an electrical engineer, and would draw attention to the statement on page 53 with regard to the low power factor, where the author pointed out that the electric generator for the induction furnace must, even with the installations of medium size, be designed for a power factor of between 0·6 and 0·7. That meant a good deal to the steel-maker, because so much more generator plant had to be provided. Certain rotary machinery would improve the power factor, but such rotating machinery required looking after. The author, for various reasons which were set out at length in the paper, recom-

mended the arc furnace, and he certainly made out a good case. Further, he backed up his arguments with a set of drawings which were not mere diagrams but were to scale—working drawings—from which any one could make a similar plant. What was specially required was a design of furnace which, when working with alternating current, gave a higher power factor or else used direct current from homopolar dynamos. A factor which told considerably against the induction furnace was the pinch effect. In a recent design of furnace, the Hering furnace, what appeared to be a successful attempt to take advantage of the pinch effect had been made. When current flowed in two adjacent conductors there was a tendency for the conductors to collapse inwards. In the induction furnace the melted metal might be considered as a number of elemental conductors, which being attracted to one another might actually pinch across and stop the continuity of current. A large enough current or irregularity in the lining of the channel would cause it. Naturally no apparatus could withstand effects produced by occurrences of that kind for any length of time. In the Hering furnaces the electrodes were in the refractory lining in the bottom, and they were connected with the secondary of a transformer. Above the electrodes there were two tubes which it was convenient to call resister tubes, and those were of course full of metal. When current flowed the metal was pulled inwards by the electrical forces, and consequently tended to lengthen. As it could not escape downwards because of the electrodes, it was driven upwards to the under side of the blanket of slag. The pinch effect in the induction furnace was so serious that it was practically impossible to melt a light-weight metal like aluminium, because it broke the circuit. Heavier metals did not pinch so readily, but all metals were of course subject to the effect. In a paper which he (Mr. Kilburn Scott) read some time ago on the Hering furnace, certain critics said they thought that the action taking place in the resister tubes would soon destroy the lining. In the April issue of *Metallurgical and Chemical Engineering*, Mr. Hering stated that, as the result of about six months' work, there had been very little wear on the resister tubes: in fact, in one case, instead of there being wear, it was the other way, and the tubes had actually become a little swollen. In any case, whether the tubes became larger or smaller, it was a very simple matter to vary the current. Another question which had been asked was as to the effect of leaving the metal in over night and allowing it to freeze. Would the metal in the tubes break and cause discontinuity? Experience showed that the metal did not break across, and so that objection had also been met. The arc furnace was certainly better than the induction furnace, but the carbon electrodes were troublesome. Everything had to be stopped to renew them, and the electrodes had a bad habit of breaking off in lumps. The supply of graphite electrodes was controlled by one firm, and consequently they were very expensive. In the Hering furnace the electrodes were of metal, generally copper; they were fixed to the furnace, and there was practically no wear on them. The author had mentioned the price of

power at 0·07d. per kilowatt-hour; but he (Mr. Kilburn Scott) would point out that in Norway the price was about 20s. per kilowatt-year, which represented about 0·027d. per kilowatt-hour. That was the point which the suppliers of electricity had to come down to. For his part, he could not see how it was going to be accomplished with fuel power stations as at present designed. Something perhaps might be achieved by the adoption of the large-sized steam turbine, such as the 25,000 kilowatt set manufactured by the Parsons Company, if used in conjunction with efficient gas-fired boilers, such as that of Professor Bone. It might be possible to bring the price of current down to 0·03d. per kilowatt-hour by allowing for the recovery of the sulphate of ammonia and other by-products. The Bone boiler had an efficiency of 90 per cent., whereas ordinary gas-fired boilers seldom gave over 50 per cent.; further, the new boiler took up only a fraction of the space. It might be said, why not employ large internal combustion engines? But so long as such engines were of the reciprocating type the output would be limited. It was not possible to conceive of a gas-engine set giving 25,000 kilowatts. A gas turbine might do so, but a gas turbine was not yet available. From the metallurgical point of view, the price charged for electrical energy in Great Britain was far too high. The only way to reduce it was to encourage the large power supply companies in every possible way. Municipal plants as at present managed would never succeed, as they were handicapped by limitations in area of supply and in being managed by committees of amateurs.

Mr. C. C. Gow (London) said that Dr. Nathusius's paper came at a moment when electric furnaces might be said to have at last attained a sound footing in Great Britain. Dr. Nathusius had brought before the Institute a furnace which resembled in many ways other furnaces of the combined arc and resistance type, but which differed from them only in the unique and ingenious method of utilising a three-phase system, enabling the bottom electrodes to work to some extent independently of the top electrodes. To satisfy those requirements Dr. Nathusius had found it necessary to introduce complications to the simple three-phase arc furnace. The only important advantage claimed was the actual generation of heat in the bath itself by the passage of a heavy and variable electric current. That, it was stated, was of first importance while the alloying metals were being added. As a rule that period lasted about 10 minutes. The heat produced by the bottom electrodes might be regulated from zero to any desired maximum, and to imitate the induction furnace during the period of alloying it would be necessary, in a 5-ton Nathusius furnace, to pass fully 300 kilowatts through the bottom electrodes: the tension of the bottom would only be 10 or 20 volts, so that the cables and transformers would have to be constructed to carry current which would be enormous for a furnace of such a size. Dr. Nathusius did not say what maximum power he intended to put through the bottom, but unless it was at least several times greater than that expended at the

surface, the advantage claimed was not fully justified. On referring to Figs. 5 and 8, it would be seen that the alloying was actually effected when only 40 and 60 kilowatts were being consumed by the bottom as against 350 and 220 by the top electrodes. He could not see that the generation of heat in the bath and in the bottom, equivalent to an average of only 50 kilowatts, was going to be of any material advantage, and certainly would not fulfil the conditions aimed at or justify the complicated additions to the simple arc furnace and its electrical equipment. With covered electrodes, a great point was made of generating the heat in the dolomite itself. That was a disadvantage, as the dolomite was likely to alter by further burning, as the author suggested, after ramming, and that would undoubtedly cause contraction, and probably destroy the solidity of the bottom. Again, generating heat in the dolomite bottom itself in a region which was close to the shell was likely to increase conduction and radiation losses very considerably. Dr. Nathusius condemned having to air-cool the transformer of an induction furnace. Surely water-cooling mild steel electrodes to prevent their melting would be a much greater source of heat loss?

Mr. A. GREINER, Vice-President, also contributed to the discussion, but subsequently sent in his remarks amplified, as a contribution to the correspondence on the paper (see p. 93).

Mr. WALTER DIXON (Glasgow) said that the thanks of the Institute were due to the author for bringing before them details of his development in electric furnaces. The time had gone by when the electric furnace was looked upon as a "fad." It had undoubtedly come to stay, but, notwithstanding the various statements and suggestions made as to the methods of working and to cheap power, he did not think the question as to whether it would replace the blast-furnace or the open-hearth furnace needed to be discussed at the moment. The electric furnace did not yet, and was not likely for a long time to, enter into competition with those, except under conditions which did not, and were not likely, readily to obtain in Great Britain.

The purpose for which the electric furnace had up to now established itself, not only as a practical, but as a commercial factor, was as a refiner, and for dealing with the higher qualities of steel. Further uses in those directions would be, and were being, found.

The paper and the discussion gave evidence of the contention between those favouring the various types of furnaces, and he (Mr. Dixon) was satisfied that good work could be done, and was being done, by the induction furnace, a type which was obviously not favoured by the author of the paper, whose good word lay in the direction of the arc furnace. He took it that the principal point which the author claimed in the consideration of his furnace was that he was able readily to use three-phase alternating current by increasing the number of arcs on the top of the furnace to three, and that three electrodes, or multiples of three, were fixed in the bottom of the furnace, for

which certain advantageous claims had been made. Whatever view the practical steel-maker took of the upper electrodes, he (Mr. Dixon) was quite satisfied that the increasing of the bottom electrodes would hardly be looked upon favourably. Hitherto, a less number than three had been viewed with suspicion, and, in considering the three or "multiples of three," he was reminded of the story of the non-musical gentleman, who, being asked by a friend whether he considered any sound worse than that of a flute, replied, "Yes! the sound of two flutes!"

To his mind, it might be accepted as a fact that the ultimate furnace would be the simplest furnace, and unless the author could show that he obtained results giving advantages in regard to economy of operation or quality of material produced which could not be obtained in other and simpler types, he doubted whether that furnace would be looked upon with favour.

The PRESIDENT, in concluding the discussion, agreed that the electric furnace had come to stay, but it was certainly doubtful whether it would compete with the open-hearth steel furnace for ordinary purposes. For special qualities of steel, there was no doubt it was the furnace of the future. In the extension of the field which would be occupied by the electric furnace, a great deal turned upon the cheap kilowatt-hour, and that was a problem which should be attacked by those interested in the electric furnace. They would all agree that the Institute was much indebted to the author of the paper, who would reply in writing to the points raised in the discussion. He proposed that a hearty vote of thanks should be accorded to Dr. Nathusius.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote that Dr. Nathusius placed great stress upon the advantage of his bottom contact arrangement, which would, however, take a great deal of heat away from the bath, hence the efficiency of the bottom contacts was very low—so low that the single advantage obtained, the higher electric resistance in the circuits through the electrode, did not justify their use. The advantage of high resistance was that a short circuit between electrode and bath (or a cold steel lump) did not cause such a high current, but that advantage was only to a very small degree obtained in Dr. Nathusius' furnace when he used covered contacts, and there was no advantage at all with exposed contacts. The conditions necessary to avoid big fluctuations of current were better established in the Soderberg three-phase electric furnace, and for Dr. Nathusius' furnace there would be required nearly twice as much copper in his cables to connect his furnace to the transformer or generator as would be used in such a furnace as the Soderberg furnace of the same capacity.

With regard to the mechanical arrangements, Dr. Nathusius stated

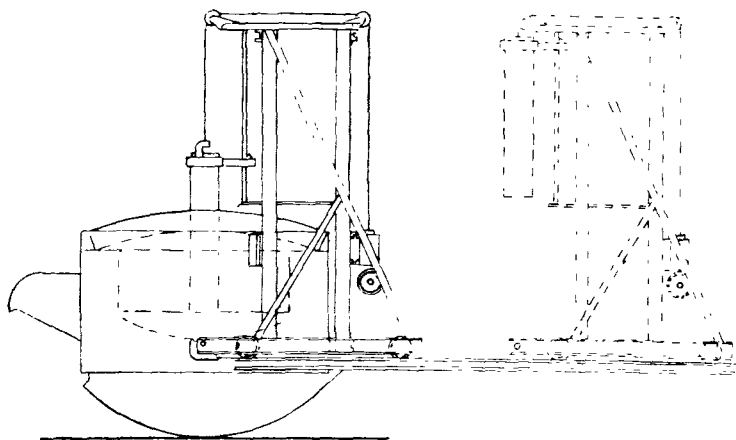
that "the breaking up of the electrodes is thus considerably reduced, as this generally takes place when the furnace is being tipped." In that statement he was entirely wrong, or if what he stated had occurred, it must have been in a very badly designed furnace. Electrodes should not break during the tipping of the furnace, more especially so if they were properly supported during the tilting by the holder and water-mantle, when there was not the slightest strain on them. The actual cause of the breaking of electrodes was generally the sudden changes of temperature during the heating up or cooling down, especially if an electrode were lifted out from the furnace, as must be done with the Nathusius furnace three or four times during every charge. It was, of course, a great drawback being unable to tilt a furnace with the electrodes in position, for, in the first instance, to lift them right up took a considerable time, and the heat radiation from the three white-hot electrodes hanging free above the furnace would be very inconvenient, not to mention the heat loss entailed. By keeping the electrodes in the furnace, sufficiently clear of the charge, the slag was kept so fluid that it would run clean out of the furnace. During the working of the furnace, therefore, all the conditions were in favour of the furnace being tilted with the electrodes in position. Dr. Nathusius was right, however, when it came to repairs or re-bricking of the furnace, where a free furnace was of great advantage over that with the electrode holders, and lifting motors attached. In the Soderberg furnace all those points had been considered, and whilst the furnace could be tilted with the electrodes in position, the whole of the mechanical parts holding those electrodes were built on a trolley, and could be disconnected from the furnace and pushed back, so that the roof could easily be changed and other repairs made. The arrangement could be seen on the sketch on p. 94, and it was both simple and cheap, whilst all the other advantages claimed by Dr. Nathusius with regard to three phase furnaces were embodied in the Soderberg furnace, in addition to which the Soderberg furnace avoided any complications with additional transformers for the bottom connections and additional measuring instruments.

MR. A. GREINER, Vice-President, contributed the following note drawn up by Mr. NOUBAER, who was specially appointed at the works of Messrs. Cockrill over the electric steel department and the physical tests laboratory, in which the latter stated at his (Mr. Greiner's) suggestion the views he held, and in which Mr. Greiner concurred, as to the application of the Nathusius furnace. The note was as follows:—

Dr. Nathusius' remarks respecting the employment of two types of electric furnaces, induction furnaces and arc furnaces, were perfectly correct and well founded. All evidence pointed to the arc furnace being the only one to possess the simplicity of construction which rendered it readily manageable and suited to fulfil its metallurgical purpose. It was also the only furnace which permitted of the

complete refining of a material charged with impurities, the induction furnace being, at most, only able to eliminate oxidisable substances, thanks to the relatively high fusibility of oxidising slags. The removal of sulphur was practically impossible in an induction furnace, no matter of what system, seeing that the chemical reaction involved necessitated the presence of a slag containing about 60 per cent. of lime and therefore exceedingly refractory.

The metallurgist required, first and foremost, an apparatus which should be simple in construction, easy to repair and to maintain, and equally easy to regulate in regard to the supply of heat. Above all, it should necessitate the minimum care, precaution, and maintenance. All metallurgical operations were apt to be sudden and to involve mishaps. They might be at the mercy of a short circuit, of injudicious handling, of ebullitions of steel, or of a sudden break-out of super-



oxidised slag. It was necessary, therefore, to have a strong and simple mechanism, but it was also necessary that the machinery should be readily subordinated to the metallurgical operations, that its regulation should automatically follow the phases of the latter, and that, in a word, the metallurgical operation itself should be the first care of the furnace staff. Now, as regards the Nathusius furnace, if in that new combined system a simple and well conceived furnace was met with, the installation and electrical equipment conveyed the notion of an instrument of precision. Too many complications would certainly constitute a difficulty in a case where simplicity was the first consideration, and it seemed to him that the metallurgist would hardly view with favour an installation intended for production, in which so accurate and delicate a system of regulating had of necessity to control the whole operation and also each separate phase.

Mr. Greiner was thoroughly convinced that the theoretical considerations from which the author started were exceedingly ingenious,

and that practice fully confirmed the theoretical conclusions he had drawn. For instance, the results given by the author with reference to the time and the consumption of electric current in making soft steel, as shown in the table, containing as little as 0.001 per cent. of sulphur and so low manganese, were extremely interesting, and had not, so far, been obtained in so short a time at Cockerill's. The system of heating through the hearth simultaneously with surface heating, at the same time maintaining an independent regulation capable of varying the intensity from zero to the predetermined maximum, was certainly a discovery which was, both from a metallurgical and electrical point of view, highly interesting as regards its originality.

The Nathusius furnace, such as had been described, would necessarily work very satisfactorily and give excellent results, both from the metallurgical point of view and from that of the consumption of electrical energy. But it was a far cry from that to claim it as metallurgically ideal. He was of opinion that a furnace such as the Girod installed at the Cockerill works, where the whole of the operations could be carried out without preoccupation as regards the regulation of the current, and where the apparatus was sufficiently strong to resist mishaps and short circuits resulting from scraping off the slag and from the introduction of the additions, was equally practical in its simplicity. The author had removed from the furnace all the electrical complications which constituted, in his opinion, the disadvantage of induction furnaces, but he had re-accumulated them at the side of the furnace, and his installation required constant regulation and most constant supervision. That criticism made, it might be admitted that not only was the conception of the furnace interesting, but the practical and economical results of the principles upon which the author's contentions were founded were fully verified. The results which he showed in Table I, were remarkable. To make homogeneous iron containing 0.001 per cent. of phosphorus and 0.01 per cent. of sulphur in 2 to 2½ hours, starting from liquid basic pig, was quite a remarkable achievement. It was impossible to do other than refer to the data given, as no information was supplied as to the composition of the charge or as to how the steels behaved in the mills. From a point of view of purification, the results given were highly interesting, and it might be granted that the dimensions of the apparatus, the distribution of the current, and the construction of the furnace had been very carefully studied. On the other hand, in the cost price in Table III, the author appeared to have worked under rather favourable circumstances, notably in regard to the consumption of 5.7 kilogrammes of electrodes distributed over 3 electrodes, and also in regard to 100 heats having been made during the life of the roof. But even with those figures the comparison of the cost with that obtained at Cockerill's, where work was only carried out during the day, was of interest. Calculations were based on the same price as that indicated by the author for the electrodes, the current, and the cost of installation

(see accompanying table). It will be seen that the cost as calculated by Dr. Nathusius was not absolutely complete, as it did not include the extraneous expenses of the furnace properly so called and inherent to its working. Those expenses ought to be added to the cost of manufacture.

Cost of Manufacture at Cockerill's per Ton of Electric Steel.

(These figures are derived from a practice extending over 3 years 2 months)

Description.	Cost at Cockerill's	Cost calcu- lated on a Double Shift.	Cost at Friedenshutte
	Shillings.	Shillings	Shillings.
Additions (similar to those indicated)	1 34	1 34	1 34
Deoxidants " " "	1 93	1 93	1 93
Refractory material	1 84	1 44	1 33
Electrodes, 6 kilogrammes at £14, 10s.	1 74	...	1 65
" 4 " at £14, 10s.	...	1 16	...
Electro-holders and cables	0 60	0 60	0 09
Wages	2 40	2 40	1 80
Current, 375 kilowatt-hours	11 25	...	7 50
" 275 " " " " " " "	...	8 25	...
Depreciation, 15 per cent. on £5900	3 00	1 66	1 70
	24 10	18 78	17 34
Labour in the reparation of the refrac- tory lining, mechanical reparation of the furnace, and electric repairs and maintenance	1 60	0 85	...
Cost of tapping (ladles, moulds, &c.)	2 40	2 40	...
Heating of the ladles	0 48	0 48	...
Skulls and ingot ends, 4 per cent. of the charge	1 48	1 48	...
Loss of metal, 3 per cent. of the charge	1 92	1 92	...
	31 98	25 91	...

With regard to the other applications of the Nathusius furnace, it was unnecessary to refer to the question of the fusion of oxidising slags, which, although it might be of use, was at the present time rather theoretical than practical. It was otherwise in regard to its utilisation for the fusion of ferro-manganese, as that question was in every sense one of up-to-date importance. All evidence showed that the electric furnace, utilising a source of heat which, if not reducing, was in any case neutral, allowed, if certain special precautions were taken, of the melting of ferro-manganese, which was highly oxidisable, out of contact with air and consequently without appreciable losses. Mr. Greiner spoke of the electric furnace in general, for all those systems could be employed, and he would be tempted to add that for that purpose, induction furnaces, such as the Röchling-Rodenhauser, were to be recommended, the utilisation of the current being better and it being possible to enclose them more thoroughly.

In any case, the melting of ferro-manganese for use in basic steel works was carried out at the Rombacher works by employing the Keller furnace, at the Gutehoffnungshütte by using the Girod furnace, at Friedenshütte by using the Nathusius furnace, and finally, at Rochling's by using the Rochling-Rodenhauser furnace. It was obvious that the use of liquid ferro-manganese as an addition possessed important advantages, possibly of an economic, but in any case of a technical nature. It was necessary, however, to guard against coming too quickly to a conclusion in regard to the considerable economy resulting from the diminution of the tonnage of ferro-manganese required by a steelworks. But even without that saving the improvement, from a metallurgical point of view, which would result from that application, was distinctly appreciable. The reaction of manganese on the oxides present took place slowly when the manganese was in a solid state, and it could be proved that it continued in the ladle down to the last ingot: its action was therefore far from regular. Further, in order that it should be complete under the conditions of current practice, it was necessary that there should be an excess of the reagent, and it was just that unnecessarily large excess which was economised, as the theoretical quantity required to produce the reaction remained the same. The products of that reaction between two liquids became eliminated much more easily, and it was possible to avoid, to a great extent, the microscopic inclusions, the presence of which was so undesirable in the steels. All those considerations showed that it was exceedingly desirable in basic steel works to reduce the oxides in an over-blown bath by means of liquid ferro-manganese poured into the ladle at the same time as the steel. Dr. Nathusius gave the cost price of the fusion of that alloy at the Friedenshütte, and the saving which could be effected per annum in the case of a saving of 30 per cent. on a total of 3300 tons of ferro-manganese used per annum. It might be said, once and for all, that that 3300 tons corresponded to the production of at least 400,000 tons of mild steel per annum, and the author had in that instance selected conditions which were highly favourable as regards the cost price. As a matter of fact, the production on that scale—that was to say, 1400 tons, more or less, per 24 hours—necessitated the fusion of about $7\frac{1}{2}$ tons of ferro-manganese per diem, which was the maximum production for a 300-kilowatt furnace, and in those conditions the figure representing the consumption of energy could be put at about 800 kilowatt-hours per ton. But if the production of, for example, 300,000 tons were taken—that was to say, 1000 tons of steel per day with $5\frac{1}{2}$ tons of ferro-manganese to be melted per 24 hours—the same 300-kilowatt furnace would be necessary and the consumption of current, either for melting the alloy or for maintaining it hot, would average from 230 to 250 kilowatts at least—that was to say, 5700 kilowatt-hours per day, or 1035 kilowatt-hours per ton of ferro-manganese. In one word, while believing that the figure for the cost price of the fusion of the ferro-manganese quoted not only by Dr. Nathusius, but by other authors, required to be closely examined, and was probably too low,

it was incontestable that the difference between the value of the ferro-manganese saved, and the cost of the fusion of the carburiser required for the liquid addition, was a real and economic one.

It should, however, be taken into account that each ton of ferro-manganese less in the ladle corresponded in effect to a ton less of steel in the ingot moulds—that is to say, a loss of, let it be assumed, 85 francs for the net cost of the basic steel, which had further to be increased by 15 francs to make up for the loss of profit on that ton of ingot metal which might have been turned into commercial products. In the case of a 30 per cent. saving in weight (such as was obtained in practice), each ton of ferro-manganese saved represented therefore a saving corresponding to its price per ton, less—

(1) The difference between the cost of melting 2.33 tons (seven-thirds) of ferro-manganese and the cost of heating 3.33 tons (ten-thirds) of that alloy.

(2) The sum of £4, representing a ton of steel lost. If, therefore, a cost price of £1 were allowed for the melting of a ton of ferro-manganese, and a cost of £8 for the value of a ton of that alloy, then, taking into account that the heating of a ton of solid ferro-manganese cost 4 shillings (the figure taken by Dr. Nathusius), each ton of ferro-manganese saved would represent—

$$£8 - [(2.33 \times £1 - 3.33 \times 4s.) + £4] = £2, 6s. 9d.$$

It might once again be pointed out that it was probable that in practice the cost of £1 per ton was considerably increased, particularly in the case of a steelworks in which only a portion of the production was mild steel, and that, if the difference between the price of ferro-manganese and that of a ton of steel—that was to say, £4—diminished, it would at once be seen that the saving realised in the weight of the additions were speedily equalised, and even surpassed, by the cost of fusion. But it might be repeated that even in that case the theoretical advantages were incontestable, and that only an electric furnace of the Nathusius or some other system would allow of that method of working being applied in steelworks.

Dr. H. NATHUSIUS wrote, in reply to Mr. A. Windsor Richards, that the process he had suggested of transferring the slag and metal in opposite directions through several furnaces was intended to be carried out on lines similar to those now followed in several large steelworks, where the metal was passed through a heated mixer (the first furnace), an open-hearth or Talbot furnace (the second furnace), and one or more electric furnaces (the third furnace). No special electric furnace was required for the fusion of the oxides: they were melted in the same electric furnace in which the steel was finished. The only factor causing increased cost of working as compared with the ordinary method of working was the regular transport of the slag from one furnace to another. But that increased cost was more than compensated for by the gain in rich slag and by the larger yield of metal. Moreover, the end-product was not Bertrand-Thiel steel or Hoesch

steel, but electric steel, seeing that it underwent final treatment in the electric furnace.

A simpler modification of the process was of course that in which the ores were melted down in a special electric furnace instead of throwing them on to the bath of molten steel. The ore became overheated, and was then charged into the liquid bath in the open-hearth or Talbot furnace. If several such furnaces were available, a larger quantity of liquid oxides could be held stored in the electric furnace. The furnace might serve also as slag mixer, and could, if required, be used for melting down special mixtures of slag which could not be treated in a gas-fired furnace, where the temperature was too low and the oxidising atmosphere so injurious. It was not to be assumed that it was more costly to melt the oxides in the electric furnace than in the open-hearth, taking into consideration in the latter case the greater length of time and loss of charge due to the slower melting down and the prolonged action of the molten slag upon the metal. With that arrangement the end-product, as Mr. Richards rightly remarked, was not electric steel. But it might nevertheless be taken for granted that on account of the energetic progress of the reaction due to overheated and liquid slag, its quality must be superior to that of ordinary open-hearth steel.

In reply to Mr. Ibbotson, the author had never contended that in using pure charges, as, in Sweden, the natural conditions permitted, good high quality steel could not be produced in the induction furnace. But it was within the author's knowledge that at east steel works in the Rhine Province, Upper Silesia, and in Austria, the induction furnace had been abandoned in favour of the arc furnace, which could only be due to practical and scientific reasons. Why high quality tool steel of 1·3 per cent. carbon could not be produced in the arc furnace was incomprehensible to him.

In reference to Mr. Saniter's remarks, covered bottom-electrodes were used both in the 5-ton and in the 2-ton Nathusius furnace at Friedenshütte, and that caused no difficulty in melting down solid charges. Latterly, at Friedenshütte solid charges of scrap mild steel had been continuously worked for weeks, and no difficulty whatever had been experienced with the covered bottom-electrodes and repairs. Bare electrodes had only been used for experimental purposes or to demonstrate to those interested how they worked. Some steel-workers were of opinion that bare electrodes were more advantageous in melting down scrap, but the author did not share that view, although both covered and bare bottom-electrodes could be used in the Nathusius furnace. It was true, as pointed out by Mr. Saniter, that the dolomite consumption of 52·5 kilogrammes per ton of steel in Table III., showing prime costs, was somewhat high. This figure was a monthly average, and included the entire remaking of the hearth, which it had unfortunately been omitted to state in the table. The normal consumption of dolomite per ton of steel with solid charges was 5 to 6 kilogrammes, and that it was higher for solid than for liquid charges was due to two causes. First, with solid charges the length of the heat was

about three times as long as with liquid charging. Secondly, the side walls, which consisted of dolomite in the Nathusius furnace, were more apt to be destroyed in recharging rough scrap, and small portions of the walls were torn down by the large lumps as they sank down in melting.

According to Mr. E. K. Scott, carbon electrodes might be dispensed with altogether, but that was opposed to the result of all practical experience which had been gained during several years with about 100 arc furnaces. The Hering furnace was only known to the author through patent specifications, and, so far as he was aware, no such furnace was working on a commercial scale. The heating of furnaces by resistance alone, the author considered impossible on account of the low resistance of the bath. So far as the author had been able to gather from the patent specification of the Hering furnace, arcs played between the surface of the metal in one division and the surface of the metal in another division at a higher or lower level. The dividing walls, it would appear, were more likely to absorb the heat than the slag, and whether such walls could resist at all the threefold chemical, thermal, and mechanical attack, was very open to doubt. The cost of electric current at 0.027d. per kilowatt hour, mentioned by Mr. Scott, surely existed only on paper. In Sweden and Norway prices for the kilowatt year only were ever spoken of. In the author's opinion it was impracticable to calculate those out for a kilowatt hour, for there was no industry which absorbed the full load uniformly the whole year round. In holiday time, or when breakdowns occurred, or, in fact, whenever the works were not running to their full capacity—and such events were quite inevitable—the theoretically calculated price would be immediately raised considerably, and that should not be overlooked.

In reply to Mr. Gow, it was not to be understood that the stage of deoxidisation and alloying in the Nathusius furnace, during which time increased heat was supplied to the bottom, lasted only ten minutes as in the open-hearth process. On the contrary, the electric refining should proceed somewhat like the crucible process, and the settling period could be extended to an hour, or longer. According to the latest improvements in the electric equipment of Nathusius furnaces, up to 50 per cent. of the total energy supplied to the furnace could, with the aid of a potential regulator, be led to the bottom-electrode circuit. The wear and tear of the bottom of a Nathusius furnace was no greater than that of arc furnaces which worked with surface heating alone, as had been practically proved by more than three years' working experience of the 5-ton furnace at Friedenshütte. A well-heated bottom naturally acted as a heat insulator to the inside of the furnace and thus hindered an escape of heat from the charge to the outside. Why a heated bottom should cause an increase in loss of heat by radiation or conduction was incomprehensible. The bottom-electrodes themselves in the Nathusius furnace were not cooled, except at that point where the conductors were connected to them by contact rings.

The question of the practicability of several electrodes had been raised by Mr. Dixon. This was so natural an arrangement that it seemed hardly to need discussion. Even the constructors and advocates of single-phase and single-electrode furnaces (such as the Giroud and the Keller types), used several electrodes (as many as four) in furnaces of larger size, which proved that it must be more advantageous. If a comparison were required, one only need say that a large room could be more uniformly heated by several heating apparatus properly distributed than by a single large one. In the latter case it would be unbearably hot in the neighbourhood of the large apparatus, and one would shiver in the remote corners. That comparison might better appeal to a metallurgist than the one suggested—between an electric furnace and a flute.

Notwithstanding the load curves shown, Mr. Adamson denied that any advantage accrued from bottom heating, but he brought forward no fact in support of his assertion. As the author was not in a position to show his furnace at work, he could only refer to the curves taken by the recording wattmeters to convince Mr. Adamson that he was in error. As would be seen from the load curve of the bottom electrode circuit on p. 75, about 60 to 70 kilowatts measured at the terminals of the bottom-electrode were actually being put into the furnace. That energy could not get lost, and could only be transferred into heat, and must, therefore, be valuable for heating the charge. Mr. Adamson surely did not propose to combat even the principle of the conservation of energy. The Soderberg furnace to which he frequently referred was unknown to the author, who was, therefore, unable to pass any opinion upon its merits.

It had been erroneously assumed by Mr. Greiner that the former consumption of 3300 tons of preheated solid ferro-manganese per annum for the deoxidation of basic Bessemer steel at Friedenshutte corresponded to a steel production of 400,000 tons of mild steel per year. As a matter of fact, only about 240,000 tons of basic Bessemer steel were being produced annually at Friedenshutte—that was about 900 tons per day—and these were the figures taken as the basis of the calculation. Yet the saving per ton of ingots was as stated. That those were actual working results was borne out by the statement of Director Boehm of Friedenshutte, who publicly confirmed them at the meeting of the Steel Works Committee of the Verein deutscher Eisenhüttenleute¹ on December 9, 1911. It should be noted that the Friedenshutte Company are the license-holders and are not in any way interested in the sale of the furnace. Mr. Greiner's calculation was also erroneous as to the reduction of saving in ferro-manganese by the amount which, when using more ferro-manganese, as in the ordinary method, might have been utilised in making commercial ingots. It could not be assumed that the object of deoxidation by means of liquid ferro-manganese was that the end-product should contain less manganese, or, in other words, that the

¹ *Stahl und Eisen*, March 11, 1912, p. 428.

subsequent analysis should show less manganese. The only object was to obtain a more energetic deoxidation and to avoid mechanical losses of ferro-manganese. But the manganese actually used for deoxidation passed as manganous oxide into the slag, and in any case was lost, as far as the commercial ingot was concerned, whether added in the liquid or solid state. But the chief source of waste was the mechanical losses of ferro-manganese particles which adhered to the slag. Those were found subsequently as solid lumps, the size of a fist, in the basic slag, and were either ground up in the mills or they broke the screens. They also sometimes dissolved in the slag without coming in contact with the metal, and were enveloped in a slag layer, so that they produced no deoxidising action on the metal. That portion of ferro-manganese was therefore lost, as far as the final product was concerned, and was never recovered in the commercial ingot either. The calculation would be correct except for those occurrences, or if it were desired to produce material lower in manganese.

Although the extreme simplicity of the Nathusius furnace was admitted, Mr. Greiner criticised the complication of the electric installation, which was placed in a separate room. That complication existed only in theory, but in practice no working arrangement could be simpler. Mr. Greiner would certainly concede that if he saw that the ferro-manganese furnace was actually served by a single unskilled man who regulated the electrodes, charged and tapped the furnace, and dealt with the slag.

The adjustment of the electrodes of the 5-ton furnace, whether working with liquid or with solid charges, was effected just as automatically as in the Heroult or Girod furnace. Mr. Greiner would probably be surprised to see that no one was on duty in the place for the purpose of regulating the so-called complicated electric apparatus. No special attention was required for that. The melter simply adjusted the apparatus as desired, and it then continued to run by itself. Perhaps Mr. Greiner took exception to the different tensions existing between the electrodes. It might here be repeated that the pressure of 110 volts (of alternating current) between the surface electrodes and pressure of $63 = \frac{110}{\sqrt{3}}$ volts (alternating current)

between the upper and lower electrodes were governed by the transformer pressure. The electric conditions were therefore precisely the same as those of a Heroult or Girod furnace. The employment of three-phase current did not affect the question in any way. The pressures, and consequently the amount of current, were changed when required by lifting or lowering the carbon electrodes. The tension between the bottom-electrodes adjusted itself exactly according to the resistance between the bottom-electrodes. Where a booster transformer with a potential regulator was used, it was adjusted in exactly the same manner as the regulating devices for the carbon electrodes. That also only required to be done once, and could be performed by the steel melter without difficulty. The electric complications

existed, therefore, in theory only, and, just as with the regenerative gas-fired furnace the melter must reverse the air and gas valves, according as a higher or lower temperature was required, in a Nathusius furnace the melter adjusted quite as simply the arc heating, and if a potential regulator were required, the bottom heating also. If the regulation of the bottom heating appeared too complicated, the booster transformer and potential regulator could be omitted, and the regulation of the current was then as simple as with the Heroult and Girod furnaces. For the bottom heating it always adjusted itself automatically. As regards durability, it could only be repeated that the cover which had last been removed from the furnace at Friedenshutte had withstood 168 charges, liquid and solid. The refining of basic Bessemer steel up to 0.05 carbon, 0.08 manganese, 0.003 phosphorus, and 0.008 sulphur could be performed without difficulty in the Nathusius furnace. Its advantage was no doubt to be ascribed to the more uniform distribution of the current and the resulting more uniform heating and better mixing due to the formation of a rotary magnetic field around every stream line.

NOTE ON THE WELDING UP OF BLOWHOLES AND CAVITIES IN STEEL INGOTS.

PART II.¹

BY J. E. STEAD, D.MET., F.R.S. (VICE-PRESIDENT).

IN the previous note, experimental data, obtained by heating and forging steel bars in which cavities had been made by drilling, showed that if the walls of the cavities were clean and bright perfect welding was easily obtained. No actual trials had at that time been made to determine whether the real blowholes in crucible steel ingots could be as perfectly welded up. Experiments have therefore been made to determine this question, and also whether cavities with oxidised walls can be welded up. It is to describe these further trials that this second note has been written.

HONEYCOMBED CRUCIBLE STEEL INGOTS.

Experiments with a honeycombed ingot of 0·5 per cent. carbon crucible steel were made at the works of Messrs. J. H. Andrew & Co. Ltd., with the assistance of the manager, Mr. J. L. Potts, and his melter, Mr. Duckenfield.

Two steel ingots from the same mixture were melted in such a way that one was honeycombed and the other sound. The sections of these are shown in Figs. 1 and 2.

The honeycombed steel rose to nearly 10 per cent. of its length after teeming, whilst the sound ingot did not rise, but contracted down its central axis.

We may assume that about 9 per cent. of the volume of the honeycombed ingot was occupied by blowhole cavities. The ingots were forged to a smaller size after heating to a wash welding temperature, estimated at not less than about 1100° C., sufficient to melt the scale on the surface, and

¹ For Part I. see *Journal of the Iron and Steel Institute*, 1911, No. I. p. 54

were divided into two parts. Half of each set of bars were reheated to 1100°C . for one hour, and were then rolled to bars 1 inch in diameter. The remaining halves were heated in the usual way without "soaking," and were also forged to 1 inch round bars. All the bars were "reeled" after forging. Portions of each of them were turned down to prisms of $\frac{7}{8}$ inch, $\frac{5}{8}$ inch, $\frac{3}{4}$ inch, and $\frac{1}{2}$ inch, and through each a hole was drilled, so as to make a series of cylinders with walls $\frac{3}{16}$ inch in thickness. A similar hole was drilled through portions of the bars which had not been reduced in diameter by turning. The cylinders thus prepared were cut up into a series of rings about $\frac{1}{4}$ inch in depth.

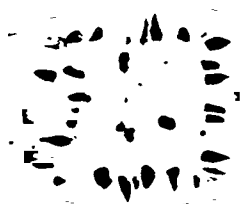


FIG. 1.—Section of Honeycombed Crucible Steel Ingot.

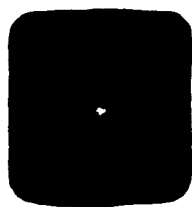


FIG. 2.—Section of Sound Crucible Steel Ingot.

The object of making these rings was to determine the degree to which they could be expanded before breaking, and to see if at their outer polished surfaces they would open out into seams on being slightly strained. The outer parts of the rings were brightly polished, and the rings were expanded by driving into them a hard taper steel drift.

The results need not be given in detail. It is sufficient to state that in no single ring after slight expansion was any unwelded steel detected, and in every case when fracture was effected the steel on each side of the parting showed evidence of contraction or plastic flow. We may conclude, therefore, that the *surfaces* of the rings were as sound in the steel from the bars of the honeycombed as they were in the steel from

the sound ingot, and as there was no difference between the bars with and without soaking, we may be certain that soaking after wash welding, in this case at least, was of no advantage, because the forging in the first instance produced as perfect welding as was possible, and no soaking afterwards could improve what was perfection. Although the welding up of the blowholes was apparently good, there was, however, a great difference in the physical properties of the rings from the respective ingots.

The rings from the sound ingot expanded on the average about 50 per cent. more before breaking than those from the honeycombed ingot, a peculiarity suggesting at first sight imperfect welding of the blowhole walls. A careful examination of the fractures revealed the presence of dull lines of microscopic fineness in the rings from the honeycombed ingot, while nothing of the kind could be detected in the steel from the sound ingot.

Further, on bending the broken rings from the honeycombed ingot, it was found that some portions of them could be bent to a greater extent without breaking than others, whilst there was not such variation in the steel from the sound ingot. In the cases where fracture occurred on slight bending these dull lines could almost always be detected on the broken surfaces, but none were present in the portions of the same rings which could be bent to a much greater degree before fracturing. Obviously these dull lines and reduced ability of the steel to extend were co-related.

As the steel contained only 0.02 and 0.03 per cent. of sulphur respectively, it seemed improbable with such a small amount of sulphur that there could be any material segregation of manganese sulphide in the blowholes. To determine whether there was or not, cross-sections of the inch bars from the sound and honeycombed steels were cut and polished, and auto-sulphur prints were obtained on bromide paper (Fig. 3). The results showed that the sulphur was distributed evenly in the bar from the sound ingot, but was segregated in the places where there had been honeycombs in the unsound ingot. Sulphur prints taken from a cut section of the honeycombed ingot itself also proved that the cavities contained sulphides. We may, I

think. be satisfied in concluding that the dull lines are co-related in some way with the sulphide segregation. Finally, sulphur prints of the fractures proved that the dull lines were rich in sulphides.

That clean faces of cavities in crucible steel can be perfectly welded together under treatment identical to that to

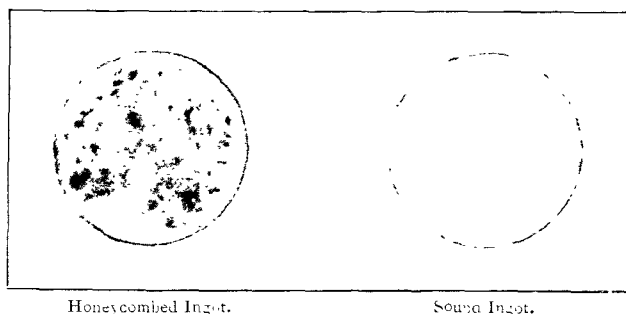


FIG. 3.—Auto-sulphur Prints.

which the honeycombed ingot was subjected has been fully proved: we are therefore satisfied that the inferior ductility in cross-sections of the bars made from the honeycombed ingot was due to the presence of sulphide of manganese threads which prevented the metallic faces from *completely* coming into contact.

BLOWHOLES WITH OXIDISED WALLS.

During the latter part of the year 1911 a series of trials was made, with the assistance of Mr. Parkin, to determine whether or not artificially formed cavities with oxidised walls could be welded up. It was taken for granted that if no carbon were present in the steel, oxidised blowholes could not be perfectly welded. In the first experiment with a 2-inch square steel bar about 8 inches in length containing 1.2 per cent. carbon, a small hole was drilled nearly to the bottom, along the central axis. The bar was then heated to redness and oxygen gas was blown down the hole, so as to oxidise the walls of the cavity. After heating to about 900°C . it was ham-

mered, so as to bring the sides of the cavity into juxtaposition. The bar was then heated to and maintained at a temperature of about 1100°C . for one hour, and was at once forged down to a smaller size. When cold it was nicked at intervals and broken at the nicks, and the fractures examined. They indicated imperfect welding near to what was originally the open end of the bar, but below this for two-thirds of the length the welding appeared to be perfect.

On microscopic examination of the polished cross-sections of the parts where welding appeared to be good it was found that the seam, originally consisting of oxide of iron, had been practically reduced to the metallic state, with the exception of minute globular dust-like inclusions, probably of iron or manganese silicate—the residue of the oxidised steel which was incapable of being reduced by the carbon. But for these excessively minute inclusions the welding was perfect. On bending a polished and etched section to open the joint, the metal at this point being lower in carbon than the surrounding mass, extended and then broke, showing a perfectly crystalline fracture, a proof that good welding had been effected.

In a second experiment with the same steel a bar was prepared as above described, with the exception that after the cavity was oxidised and closed the bar was heated to 950°C . for three hours. It was then cut in half; one-half was retained for examination, the other was reheated at 1100°C . for one hour, and without forging, it was allowed to cool. It was again cut into two portions, one of which was heated to 1100°C ., and then forged down to a smaller size. The other part was reserved for examination. Each of the three specimens was sectioned, polished, and examined microscopically without etching.

Figs. 4 and 5, representing magnifications of 330 diameters, show that by heating at 950°C . the carbon of the steel reduced the iron scale to metallic iron, which remained in separate grains, surrounded either by some slight amount of unreduced oxide, or gaseous spaces, or by both.

On attempting to bend the specimens, the grains at once separated: there was no cohesion, they had not completely

crystallised together—a result not surprising, for the volume of metallic iron is less than that of its oxide.

Fig. 6 represents the same bar as the last after heating to 1100° C. for one hour. The drawing shows that the greater mass of the reduced iron grains had crystallised together and pressed to one side the intervening gases, and compelled them to segregate into relatively large bubbles at a considerable distance from each other. The microstructure of the joint in the third portion, which had been reheated to and forged from 1100° C., was identical with that in the bar of the first experiment, which had been heated to 1100° C. for one hour and then forged to a smaller size, and is represented in Fig. 7.

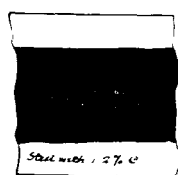


FIG. 4.—Section through closed-up oxidised cavity. Black part represents cinder; white part, metal.



FIG. 5.—Same as Fig. 4 after heating for 3 hours at 950° C. Dark parts are actual spaces and unreduced slag inclusions.



FIG. 6.—Same as Fig. 5 after heating for 1 hour at 1100° C. Dark parts are actual spaces and unreduced slag inclusions.



FIG. 7.—Same as Fig. 6 after heating to 1100° C. and forging down to smaller size. Dark parts are slag inclusions.

The welding was perfect, with the exception of the minute globular inclusions previously referred to.

In a third experiment the steel bar was treated exactly as in the first, but the bar itself contained only 0.50 per cent. carbon. The welding was found to be complete, but the joint previously occupied by the scale now consisted of carbonless ferrite, and the adjacent steel contained less carbon than the mass of the steel itself. These results show, as was anticipated, that if the walls of the cavities are not too thickly scaled and a sufficient quantity of carbon is in the steel the scale itself can be reduced practically entirely to the metallic state, and this can be welded up to the sides of what was originally the cavity.

It is generally assumed that blowholes, which terminate on one side through the outer skin of the envelope of steel ingots, having access to oxidising gases, do get so severely oxidised on their walls that no welding of the cell walls occurs, and that in rolling out they are simply extended and appear at the surface of the rolled sections as rokes, which penetrate to the full depth of the extended blowholes.

The presence of the microscopic dark inclusions observed in the welded joints (Fig. 7) led to the examination of many sections of steel which had evidently been rolled from honey-combed ingots. It was believed that if any of the oxide initially filling the blowholes had been reduced to the metallic state and welded to the surrounding steel, similar inclusions would be discovered. The results of these examinations proved beyond doubt that in a very large number of cases in steel containing between 0.25 per cent. and 0.5 per cent. carbon, these microscopic inclusions were present, and were located in the surrounding layer of ferrite immediately below the lower part of the surface rokes. It is only necessary to describe a single instance. This was a railway axle, on the surface of which there was ample evidence of pre-existing cutaneous blowholes in the ingot, for at intervals there were longitudinal lines or fine grooves an inch or more in length. A cross-section vertical to the surface, after polishing, was sufficient to reveal the position and depth of these rokes. The depth varied from one-hundredth to one-fifth of an inch. The outer envelope was completely decarburised, as is usual in low and medium carbon steels which have been reheated in an oxidising atmosphere previous to forging or rolling.

There was a complete absence of the minute inclusions in this envelope: the steel contained no carbon, but the ferrite immediately in contact with the scale, and for a little distance beyond, contained minute globular inclusions, whilst at a greater distance the crystals of iron contained none.

The crystals of one zone penetrated into the other and were common to each—in other words, one part of the crystals at the border-line contained inclusions, whilst the other contained none.

The following diagrammatic sketch (Fig. 8) explains better

than words the appearance under the microscope. The photograph (Fig. 9), taken at the point corresponding to A in the sketch, clearly shows the globular inclusions.

There can be little doubt that the ferrite containing the inclusions surrounding the remaining unreduced oxide was at one time oxide or scale in a blowhole, that this was reduced practically entirely to the metallic state by the carbon in the adjacent steel, and that the particles of reduced iron had

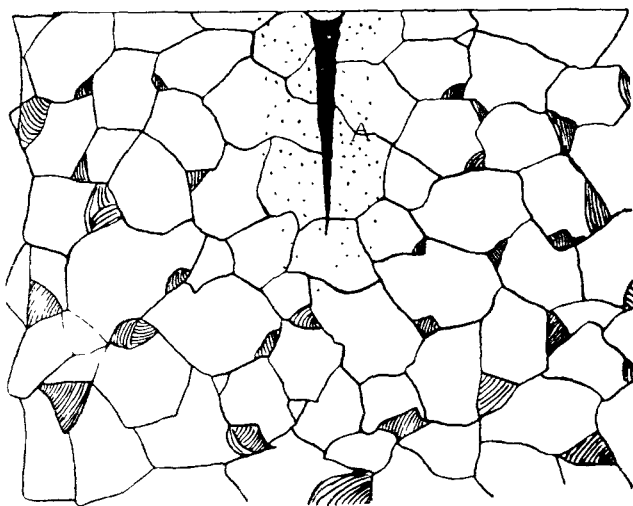


FIG. 8.—Diagrammatic Sketch showing Section of a Roke in a Steel Axle, with surrounding of reduced scale.

crystallised together and to the steel itself, producing a practically perfect weld—indeed on straining, so as to bend the steel, there was no opening out at the junction of the two zones. The minute inclusions are the residual portion of the scale which could not be reduced by carbon or carbon monoxide at the temperature at which the steel had been heated and rolled.

In conclusion it seems reasonable to believe that under the ordinary treatment to which honeycombed ingots of steel are heated and rolled internal small cavities or blowholes do become perfectly welded up, provided there is an absence of

sulphide segregations, and that even when these segregations are present, as they are not in continuous lines but occur only at intervals, the clean metallic faces between them come into contact and weld together.

It seems also justifiable to conclude that surface blowholes which become oxidised on their walls during the heating and rolling of the ingot, do become more or less completely

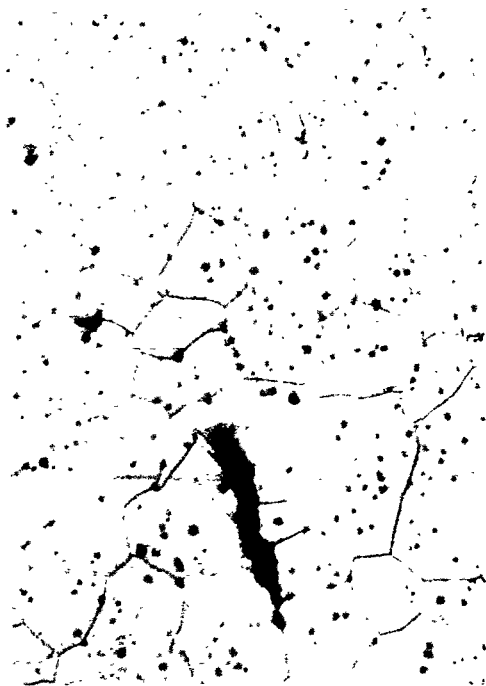


FIG. 9.—Actual Photograph near region A in Fig. 8.

welded. The conditions favourable to this welding must be a sufficiently high temperature, and maintenance of the steel at that temperature for a long enough period after the cavities have been closed to admit of the carbon in the adjacent steel being afforded the opportunity to reduce the oxide scale.

It must be pointed out that much more work is still required and trials made with other classes of steel and similar steels which have had treatment varying from what has been

described in this note, as it is certain under some conditions the blowholes may not be welded up.



FIG. 10.—Section along a drawn-out blowhole showing that the crystals are continuous from one side to the other.

The methods described and the observations made will, it is hoped, facilitate the work of others who take up this branch of research.



FIG. 11.—Longitudinal section of a drawn-out blowhole containing sulphide segregation, after polishing and bending. The dark irregular line illustrates where the steel opened out along a sulphide thread. The dark lenticular-shaped portion is a cavity once filled by sulphide of manganese, which became loosened on bending and dropped out afterwards.

In conclusion, I must acknowledge the assistance of the gentlemen mentioned in the text of this report, without which it would have been impossible to present this note.

DISCUSSION.

Professor J. O. ARNOLD, F.R.S., Bessemer Medallist, said that he entirely agreed with the views put forward by Dr. Stead, and it had to be admitted that occasionally blowholes were produced in the course of steel manufacture. He could speak definitely upon that point, because he had seen such blowholes. Dr. Stead had produced a remarkably bad ingot, and he (Professor Arnold) hoped it had only been made for the purposes of the investigation. Assuming that to be the case, he could assure Dr. Stead that they had made much worse ingots in the University Steel Works at Sheffield, and they were quite prepared to compete with Dr. Stead in badness. The points raised about low carbon steel might have a very grave application in connection with tubes for water-tube boilers. For such purposes 4-inch tubes from Swedish ingots were employed, and a blowhole in the ingot produced, in rolling down, minute roaks down the tube, and it was possible that a burst might take place. He had seen examples of that in Admiralty and other tubes. From a practical point of view it was necessary to remember that in that vital part of a ship, blowholes of that description could not be welded out.

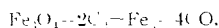
The PRESIDENT, in concluding the discussion on the paper, said that he thought the Institute should be very grateful to Dr. Stead for his contribution. Speaking as a steel-maker, he was able to assure the meeting that steelmakers did their best to avoid the existence of blowholes, but, admitting that they did sometimes exist, it was interesting to know that, under certain conditions, they could be welded. The subject was of very great importance to those members who were engaged in the heavy steel trade, and if Dr. Stead would extend his investigation to Bessemer and open-hearth ingots, steel-makers would be grateful to him. He assumed that the investigation with which the paper dealt had been carried out on crucible ingots.

CORRESPONDENCE.

Mr. W. J. FOSTER (Darlaston) wrote that at the last May meeting he took the opportunity of discussing, in writing, Dr. Stead's paper on blowholes, but unfortunately his views had evidently been misconstrued. What he intended to convey was that most of the holes in iron and steel castings, including ingots, were brought about by natural physical causes, due to simple liquid contraction through the various stages of cooling after casting, a phenomenon absolutely independent of blowholes brought into existence by the evolution of gaseous matter. He mentioned that because he thought it would be advisable first of all to determine the difference between the two

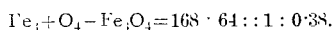
forces (which might be either those producing a vacuum or pressure) by which those holes or cavities were formed, so that unnecessary investigations for the determination of gaseous matter in certain casting might be avoided. Further, he might add that when that question was discussed between several of his friendly critics and himself some few years ago, the question was raised as to the cause of the holes in a honeycombed No. 4 pig iron. He then suggested that the direct cause of those holes was simply liquid contraction, and although his remarks were somewhat ridiculed, he was pleased to say that his friends now fully agreed that the primary cause of those holes was no other than liquid contraction. On the other hand, it would be absurd to attempt to dispute the existence of gaseous matter in a soft overblown steel ingot or casting where an excess of gaseous matter was present. In reply to his remarks Dr. Stead suggested that if the holes were brought about by liquid contraction, which if internally concealed would necessarily be under vacuum, and assuming that there had been no path or channel caused during the period of contraction that would allow air to enter—which would undoubtedly oxidise the wall or outer skin of the hole—such hole or holes would be welded up perfectly. He (Mr. Foster) agreed with Dr. Stead's remarks, and thought that if such castings were heated to a sufficiently high temperature to forge, they could be welded into a perfectly homogeneous mass. That ought to be a good test to distinguish the difference between a hole which had been oxidised by gaseous matter, and a hole which had absolutely been created by liquid contraction in a perfect vacuum. With reference to the question of 0.5 per cent. of carbon in a steel being capable of preventing internal oxidation of the iron in a blowhole under the conditions mentioned by Dr. Stead, he (Mr. Foster) was inclined to think that that opened out a field for research that required a great deal of thought from a thermo-chemical point of view.

In solving a problem of that nature, thermo-chemists had constantly to take into consideration the influence of mass. For example, it would be interesting to consider the possibility of the reduction of oxide of iron (Fe_3O_4), which would form the oxidised inner coating of the supposed blowhole. He had calculated theoretically that oxide of iron was reduced, in a mass of steel containing 0.5 per cent. of carbon, by the following equation:—



The units in a mass of such a steel calculated by weight necessary to be brought into the sphere of chemical action for the reduction of Fe_3O_4 derived from the oxidation of one unit of the same steel would be the enormous mass of 101 units. Under such conditions it was difficult to see how complete reduction could possibly have taken place in a semi-fused mass of steel of the carbon contents mentioned, particularly seeing that the reaction was extremely endothermic, and had therefore a negative heat value under the conditions mentioned.

One unit of steel oxidised :—

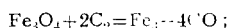


One unit of steel containing 0.5 per cent. of carbon :—

$$100 : 0.5 :: 1 : 0.005.$$

\therefore 0.38 unit of oxygen required $\frac{0.38}{0.005} = 76$ units of 0.5 per cent. of carbon steel.

Units of steel required when the following equation was completed :—



thus

$$\text{O} \div \text{C} = \text{CO} = 16 : 12 :: 1 : 0.75;$$

$$\therefore \frac{76 \times 1}{0.75} = 101 \text{ units required.}$$

In conclusion, he hoped that Dr. Stead would give the matter due consideration, as he (Mr. Foster) was of opinion that it would lead to a valuable field of research for future investigation.

MR. C. H. RIDSDALE (Linthorpe) wrote that the members ought to be very much obliged to Dr. Stead for having carried out those further definite and systematic experiments with blowholes and cavities synthetically produced and subjected to welding treatment under known conditions, as an independent check upon the conclusions which practical men had arrived at from observation in actual works experience. It was also comforting to himself to find with regard to the points on which Dr. Stead had made pronouncements that they were in entire accord with what he (and no doubt many others) already held with regard to the effect of rolling on ingots under ordinary mill conditions—namely, that the ordinary blowholes (invariably present) became for practical purposes welded up. He might add also, from his own experience of steel ranging from a trace to 0.50 per cent. of carbon, that even cracks, the surface of which were oxidised—such as those due to rolling an ingot whilst too “fresh”—did not, in the rolling process, tend to go deeper, but to come to the surface: changing their vertical to an almost horizontal direction, and, unless very deep, scaling or flaking off altogether, whilst if too deep for that they exhibited surface defects, and the piece became rejected. He (Mr. Ridsdale) had, however, some years before to report on some foreign ingots, intended for the manufacture of boiler tubes, which contained deep vertical roaks, oxidised internally, and in which the particular process of making into tubes had left the roaks still almost vertical, and exactly as Dr. Stead described. Below a small visible surface defect for a considerable distance welding had taken place, which when sectioned and polished was, to the eye, apparently perfect, but on etching, and under the microscope, was clearly imperfect—indeed Dr. Stead's words, “the seam originally consisting of oxide of iron had been practically reduced to the metallic state . . .,” and, . . . “on attempting to bend . . . the grain at once separated, there was no cohesion . . .” entirely described

it. That was obviously a case where apparent welding up might give a false sense of security, as the tube might easily burst when in service. He was pleased to see that Dr. Stead's experiments showed that "soaking" after wash-welding was of no advantage"—because he (Mr. Ridsdale) was of opinion that, though in practice many people seemed fond of it, it never did good, but always, if continued long enough, serious harm to steel. Erroneous impressions on the subject of blowholes existed in many quarters, and thanks were due to Dr. Stead for demonstrating in a clear way matters which would go far to remove some of those impressions.

Dr. STEAD stated, in answer to Mr. Foster's remarks, that it should be clearly understood that oxidised blowholes could only be welded up provided the time and temperature were suitable to admit of the carbon of the steel reducing the oxide. When an ingot was rolled off from a relatively low temperature without reheating afterwards, it was doubtful whether the welding up of oxidised blowholes would be satisfactory. Reheating in an annealing furnace after the forging or rolling would undoubtedly favour the reduction of the oxide and more perfect welding. The remarks of Mr. Foster with regard to thermo-chemical reaction were interesting. It must be remembered, however, that whilst the amount of oxide of iron on the sides of closed-up blowholes might be exceedingly minute, the mass of the surrounding steel was very great. With carbon, even as low as 0.2 or 0.3 per cent. in the steel, there would be an excess of what was required to reduce oxide films.

Replying to Mr. Ridsdale's remarks, Dr. Stead stated that the quotation he had made had reference to steel which had been reheated for three hours at 950°C ., but without forging afterwards, in which the grains of reduced iron had not crystallised together. The result was, however, different in the case of heating the same bar for one hour at 1100°C . In that case the grains had crystallised together, but the weld was unsound. After again heating to 1100°C . and forging down to smaller size, the unsoundness disappeared, and the joint did not open out on attempting to bend the specimen. He was glad to find that Mr. Ridsdale, as a practical man, had arrived at the same conclusion as to the welding-up of blowholes as he (Dr. Stead) had done, but he would point out that practical men were far from being unanimous upon that point, and he desired clearly to point out that the welding described in his paper was complete only under the conditions he had stated. It was possible that under other conditions, such as lower temperature of heating, welding would not be so perfect.

NOTES ON A BLOOM OF ROMAN IRON FOUND
AT CORSTOPTITUM (CORBRIDGE).

PRESENTED BY SIR HUGH BELL, BART. (PAST-PRESIDENT).

DURING the recent exploration of the Romano-British site of Corstopitum, one of the largest masses of Roman wrought iron ever found in England was unearthed in 1909, and it was to describe this that this note was prepared.

The exploration was organised by a committee of prominent archaeologists, with His Grace the Duke of Northumberland as President, and Mr. R. H. Forster, M.A., F.S.A., as Superintendent to the actual works. Excavations were conducted during the years 1906-1911, and will be continued this summer. Full reports have been issued yearly in *Archæologia Aeliana* by Mr. Forster and others. The finding of the bloom is described there in the volume for 1910 (pp. 240, 265).

An excellent short account of what was done and discovered in the years 1907-1909 has been written by the Superintendent and Secretary. In this account¹ an introductory statement is given describing the position of Corstopitum. This I now propose to quote.

"The Roman Corstopitum, though it is situated about two and a half miles to the south of the line of the Murus, owes its importance to, and no doubt acted as, a supply base for the soldiers who garrisoned the wall. It lies immediately to the west of the village of Corbridge, on the north bank of the Tyne, at the point where a Roman bridge, half a mile west of that now in use, carried Dere or Watling Street across the river. It was obviously so placed to command the great Roman road which formed the line of communication between York (Eboracum), the headquarters of the Sixth Legion, and the eastern part of the northern province: this road enters County Durham at Piercebridge, passes Binchester (Vinovia), Lanchester, and Eborchester (Vindomora), and here crosses the

¹ *Corstopitum: Report on the Excavations in 1909*. By R. H. Forster and W. H. Knowles. Newcastle-upon-Tyne: Andrew Reid & Co., Ltd., 1910.

Tyne to Corstopitum. Thence it continued northwards by Risingham (Habitancum), High Rochester (Bremenium), and Chew Green into Scotland, and reached Newstead and the wall of Pius beyond it.

"The name Corstopitum occurs in the Antonine Itinerary, or Road Book of Roman Britain, as the first *mansio* or halting place south of Bremenium which seems, at the date when this part of the Itinerary was compiled, to have been on the northern frontier."

In conclusion, in this short report, the authors state "that Corstopitum was not an ordinary fortress but rather a town penetrated by military elements. The two buttressed granaries, of exceptional size, are distinctly military features, as is no doubt the large massive building to the east of them. These appear rather to have been intruded on the city, thereby converting the place into a large depot, a service which it probably continued to fulfil from the time when Antoninus Pius made his advances northward until Septimius Severus similarly conducted expeditions against the Caledonians. The presence of numerous coins of later date than A.D. 200 in the granaries possibly occurs in consequence of these buildings being subsequently used for other purposes than the storage of grain. The repeated finds of burnt coins dating up to A.D. 340, and a scarcity for a period thereafter denote a destruction by fire, while the absence of coins after about the year 385 narrows to within a few years the period when the city was abandoned. It is, of course, not possible to assign these dates to the periods when the various road and floor levels were constructed, but it is all new evidence to be carefully noted as revealing the history of the occupation of Northern Britain."

In an historical account of the manufacture of iron in the North of England, by I. Lowthian Bell,¹ it is pointed out that "the labours of Hodgson, Wallis, and others leave little or no doubt that the smelting or reduction of iron ore was carried on to a considerable extent in this part of the country during its occupation by the Romans. Vast heaps of iron scorie

¹ *The Industrial Resources of the Tyne, Wear, and Tees* (Reports read before the British Association in 1863), p. 82. Second edition. London, 1864.

may be seen on the moors in the parishes of Lanchester and Chester-le-Street, in the county of Durham, and in the valleys of the Reed and the Tyne; on the mountain limestone in Northumberland. It is remarkable that none of these are very remote from one or other of the Roman stations which are scattered over these two counties. The same observations respecting an early use are, to some extent, applicable to the lias ironstone, and no doubt proper investigation would indicate a similar state of things wherever iron ores were near the surface, and the state of society required the metal they contained."

The following metallurgical notes by Professor H. Louis were included in the general report for 1909 (*Archæologia Arelana*, 1910, p. 265), in which he gives the results of his personal investigations, and an opinion as to the origin of the iron bloom:—

NOTES BY PROFESSOR HENRY LOUIS.

"The most interesting object found was a block of iron (see Plate IV. Fig. 1), 3 feet 4 inches long by 7 inches square at one end, which was rough and rather spongy, tapering down to about $4\frac{1}{2}$ inches square at the other end, which was well rounded. In order to get samples for metallographic examination, pieces were cut out with chisels and hack saws; underneath a superficial skin of hard rusty scale, about $\frac{1}{4}$ inch thick, the metal was found to be quite clean, sound, soft and tough. To obtain samples for chemical analysis, $\frac{1}{2}$ -inch holes were drilled about 10 inches from the smaller end and 2 inches from the edge of the block: for the first $1\frac{1}{4}$ inch the metal was clean and sound, but on drilling deeper, the interior of the bar was found to be honeycombed and spongy. Only the outer sound portion of the metal was subjected to a complete analysis,¹ which gave the following results:—

	Per Cent.
Carbon	0.061
Silicon	nil
Manganese	nil
Sulphur	0.008
Phosphorus	0.063
Silica in the form of slag	0.32

¹ Analysis by Mr. H. Dean, M.Sc., A.R.S.M., in the Metallurgical Laboratory, Armstrong College.

“The inner spongy portion of the block contained 0·14 per cent. of carbon.

“The microstructure showed characteristic grains of ferrite, with the planes of separation of the crystals very well marked. Some of the grains of ferrite show a well-defined series of parallel lines running across the crystals. The outer edge of the sample shows a small quantity of pearlite between the grains of ferrite; there are also numerous patches of slag, generally elongated in the direction of the longer axis of the block (see Plates II. and III.).

“I have little doubt that this block was made by welding together comparatively small lumps of iron produced by a direct reduction process in small charcoal fires: there is no reason why the ores employed may not have been the local blackband ironstones of the carboniferous series, some of which outcrop in this part of the country. The block of iron was probably used for an anvil, and I am inclined to think that the iron was probably smelted in the woods, near the outcrop of a seam of ironstone and was brought into the Corbridge settlement to be there worked up and forged into various articles: the anvil block would in that case have been used for such forgings.”

Chemical analyses and microscopical investigations on the bloom have since been carried out by Dr. J. E. Stead, F.R.S., who has kindly supplied the following details:

NOTE BY DR. J. E. STEAD, F.R.S.

The bloom measured 39 inches between the extremities of the metallic portion; its diameter at the widest part was 7 by 8 inches, and at the smallest part 5 by $4\frac{1}{2}$ inches. It weighed 3 cwt 8 lb. but as it was thickly coated with rust, and contained oxidised slag in the hollow upper part also much imprisoned slag, it is probable that the nett weight of the metallic part was not more than 3 cwt.

On close examination of the external surface, there was evidence that the bloom had been built up and welded in sections as suggested by Professor Louis, as the terminations of some of the laps could be easily seen.

As it was of great interest to find out exactly how the mass had been built up, whether the several pieces used in its construction were homogeneous, and whether the welds had been well made, the committee decided to have the bloom sawn through its entire length so that a thorough examination could be made. The bloom was therefore sent to Middlesbrough, and Messrs. W. Shaw & Co. having kindly consented to do the sawing by the aid of their powerful band saw, it was removed to the Wellington Foundry, where it was cut under the superintendence of myself and my assistants.

Owing to the presence of enclosed slag there was difficulty in sawing it, so much so that before the sawing was completed no less than six band saws were required. The sawings from each 6 inches of bloom cut were reserved for separate analysis.

The cut faces were planed, polished, and photographed, and were afterwards etched with a 20 per cent. solution of nitric acid and water, and were again photographed. An auto-sulphur print was taken of one of the faces previous to etching with nitric acid, and this showed considerable darkening corresponding to the parts where the imprisoned slag was located, but a very slight and uniform colouration throughout the whole area of the metallic portion. This is reproduced in Plate IV. Fig. 2, showing that, while the metal contained a very minute quantity of sulphur, the slag was rich in that element, a result confirmed afterwards by analysis. After the faces had been strongly etched, it was easy to trace the lines of welding, not because of the imperfection of the welding, which was generally very good indeed, as can be seen by the photographs, but on account of the slight physical difference in character of the metal on the sides of the junctions. In order to show how the mass was built up, careful tracings were made by Messrs. Harrison and Jobson of Middlesbrough. These are reproduced in Plate V. Figs. 1 and 2. From these sections it is perfectly clear how the pieces were joined together and the bloom built up. In general terms, slabs approximately lenticular in section were employed. After the smaller end was made, the piece at this stage probably had a

similar appearance and shape to the upper end of the bloom in the condition in which it was found in the furnace with projecting taper pieces. After forming the foundation piece, two slabs must have been inserted *vis-à-vis* and the mass then heated to welding temperature, after which it was removed and welded by hammering, but by what kind of implements there is no evidence. Step by step this process was repeated until the bloom of the size and dimensions as described were obtained, *plus*, of course, the portion which had been removed by subsequent rusting.

It seems probable that the bloom was in course of further development at the time it was left in the furnace, a conjecture justified by the projection of the pieces of metal at the upper or thick end, the fact that it was this end that was uppermost in the furnace, and also to its very unfinished character. The presence of large cavities in the central shaft of the bloom clearly proves that the mechanical force used in welding it was not great, probably because there were no powerful agencies available.

On examining the etched sections there were noticed certain areas coloured brown and these on microscopic examination were proved to contain between 0.5 and 1.5 per cent. carbon, and analyses taken from these areas by drilling gave carbon respectively 0.75, 0.80, and 1.6 per cent. (See photomicrographs, Plate VI. Figs. 1 and 2.) The metal at these points is really steel possibly produced by the carburisation of the spongy iron initially produced when the ore was being reduced in a charcoal fire, and probably the result of accident rather than design. The upper central portion of the bloom was little better than a mixture of iron and cinder similar in character to a spongy ball of puddled iron. The analysis of the interposed cinder proves that the cinder itself is not a refuse slag, but probably oxide produced by the oxidation of almost pure iron, which might be the result of heating a large number of small pieces of the iron preparatory to welding.

The photographs in Plate VII. Figs. 1 and 2 represent the character of the metal at points A and B, natural size. In Fig. 1 showing the homogeneous part there is striking evidence of the almost complete absence of included slag, which is most

remarkable in view of the fact that the thickness of the metal at this part was so great (measuring 4 inches); and one can only conclude that the whole of this was obtained from a single mass of spongy material worked up in the furnace itself by pressing and squeezing during a considerable period, and not produced by the welding together of several separate pieces.

Plate VII. Fig. 2 indicates a very different character, as the amount of enclosed cinder is excessive. It probably represents what the sounder metal really was previous to the process of squeezing and proper working.

The Furnace in which the Bloom was found.—Judging from the description in the full Report for 1909 by Mr. Förster,¹ the furnace was about 6 feet in diameter, circular in form with a narrow opening in front; the depth is not given, but, judging from the illustration shown in Plate VIII., it was about 5 feet from the top of the wall to the hearth.

In a communication since received from Professor Louis, who was privileged to examine the furnace and surroundings, he states, when referring to the so-called ‘furnace’ :—

“Whatever it was, I am convinced of one thing it was not, and that is a smelting-furnace. The walls were made of rough stone set in common clay reddened by heat, that is to say, which had been heated somewhat above the temperature of dehydration of the clay, but had not been thoroughly burnt in the sense that an ordinary brick is. If this clay had been exposed to a welding heat it would have been fused, or at any rate vitrified. It is barely possible that the structure as it stands might have been the outer wall of a furnace, from which the inner lining or furnace proper had been removed, but the absence of tuyere holes seems to me definitely to dispose of this hypothesis. I now imagine it to have been the substructure of a forge used in welding up the bloom; the bloom will have been stood upright in the middle of the wall and secured with stones, clay, &c.; round the upper part of the bloom that was being forged, a light wall, probably of clay, will have been built, and into this clay will have been built two or three of the clay nozzles found at

¹ *Archæologia Aeliana*, Third Series, 1910, vol. vi. pp. 240, 265.

Corstopitum (see sketch, Fig. 1); by this means a welding heat will have been got round the upper part of the bloom, when the upper wall would probably be pulled down and the bloom hammered. A number of these clay nozzles were found, a photograph of some of these being appended (Fig. 2): they are very like what I have seen used in the Far East for similar purposes. I also send you three photomicrographs (Plates II. and III.) taken in our laboratory, which enabled me to determine the nature of the iron. I have little doubt in my mind that the ore smelted was from the outcrop of the local blackbands:

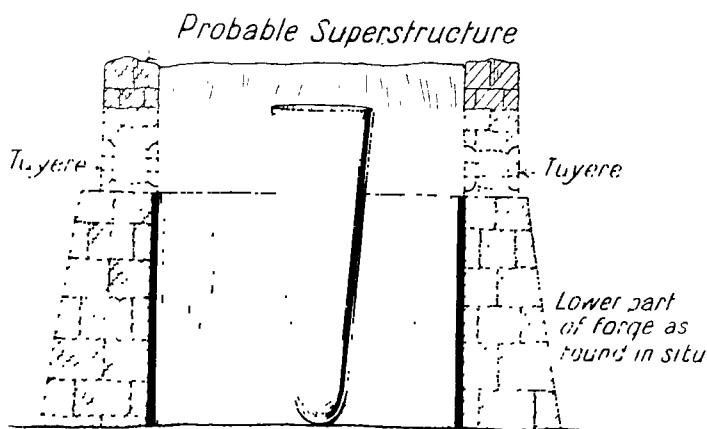


FIG. 1.—Section through Furnace, showing probable method of forging the mass of Iron

there is, for example, a famous bed of ironstone just below the base of the coal-measures proper that was worked for many years in the Derwent valley, not many miles from Corstopitum, and other similar deposits outcrop all round about that site (see accompanying map, Plate IX.). The well-known Ridsdale ironstone, mentioned above by Sir I. Lowthian Bell, forms a conspicuous band that actually runs across the Roman road and is close to the site of the Roman station *Habitancum*: this could well have been a source of the iron in question. Obviously if iron were made direct from an ore such as I have suggested, the iron would be low in phosphorus, which

element would pass direct into the slag (*vide* analysis of 'Cinder from Cavity'). I have conjectured that this block of iron was intended to be used as a stake anvil, and I still hold this to be quite possible. In this case the lower end would have been undergoing repair or being lengthened at the time that it was left.

"I am quite convinced in my own mind that the origin that I have assigned to this iron is correct, and can see no

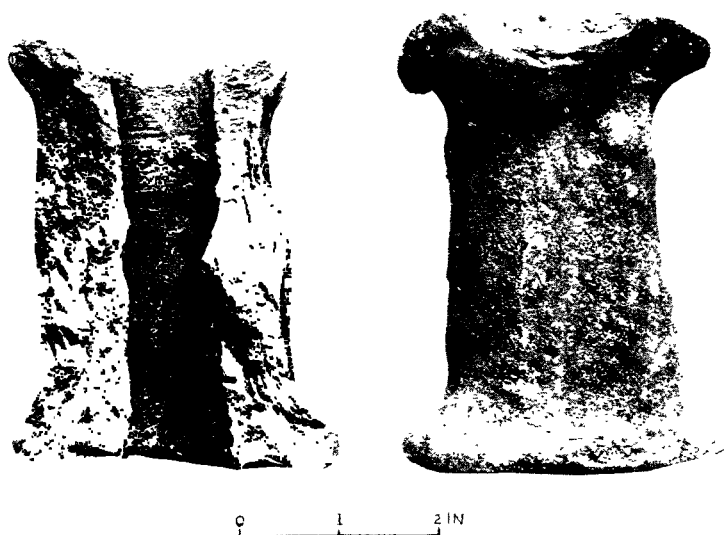


FIG. 2 —Nozzles made of Baked Clay, found close to Forge at Corstopitum.

argument at present against it. It is quite certain from what I have seen of direct process work, that if this were a smelting furnace site there would have been a considerable accumulation of slags round about it, and I cannot believe that the careful search I made would not have found any had such existed; it seems to me much more natural that the Romans smelted their little balls of iron with charcoal at or near the outcrop of the local ores, and transported the cakes of spongy iron thus produced into the town of Corstopitum to be worked up. I have seen quite similar operations in India. the famous

Delhi Pillar¹ is supposed to have been made in the same way as I am supposing was used for this Roman bloom. There seems to be no good reason why the practical Romans should have brought their ore and charcoal into the township to smelt them there, instead of building smelting works on a more convenient spot, as the condition of the country appears to have been peaceable enough to allow them to carry on their smelting operations in the woods."

The sawings, as they left the machine, were mixed with the lubricating water solution of soap and particles of free cinder. After separating the free metal with a magnet the cinder-freed iron was washed with water, then alcohol, and finally with ether; and after drying was analysed. The six separate portions were tested for carbon and phosphorus, and equal portions of each were mixed together for more thorough analysis.

CHEMICAL ANALYSIS

By J. E. STEAD.

Analysis of Separate Portions.

	Lower End.			Top End.	
	1	2	3.	4.	5
	Per Cent.	Per Cent.	Per Cent.	Per Cent	Per Cent
Carbon . . .	0 07	0 02	0 025	0 075	0 295
Phosphorus	0 038	0 046	0 051	0 046	0 041

Average Analysis.

	Per Cent
Carbon . . .	0 097
Manganese	0 040
Silicon . . .	0 046
Sulphur . . .	0 025
Phosphorus	0 044
Arsenic . . .	0 049
Copper	0 010
Cinder . . .	0 380

¹ See the interesting paper by Sir Robert Hadfield on "Sinhalese Iron and Steel of Ancient Origin," contributed to the present meeting of the Iron and Steel Institute.

Analysis of cinder separated from the metal at point A on the diagram and from one of the cavities :—

	Point A. Per Cent.	From Cavity. Per Cent.
Iron	69.30	...
Silica	0.60	10.60
Phosphoric acid	0.09	0.42

Rust and Cinder mixed from Top End.

	Per Cent.
Peroxide of iron	58.000
Protoxide of iron	21.407
Protoxide of manganese	0.209
Alumina	1.240
Lime	0.800
Magnesia	0.595
Silica	7.450
Sulphuric acid	0.170
Sulphur	0.264
Phosphoric acid	0.174
Oxide of copper	trace
Potash	0.077
Soda	0.199
Arsenic	0.030
Chlorine	0.985
Carbonic acid	2.200
Combined water	6.180
	<hr/> 99.980 <hr/>
	Per Cent.
Iron	57.25
Sulphur	0.068
Phosphorus	0.076

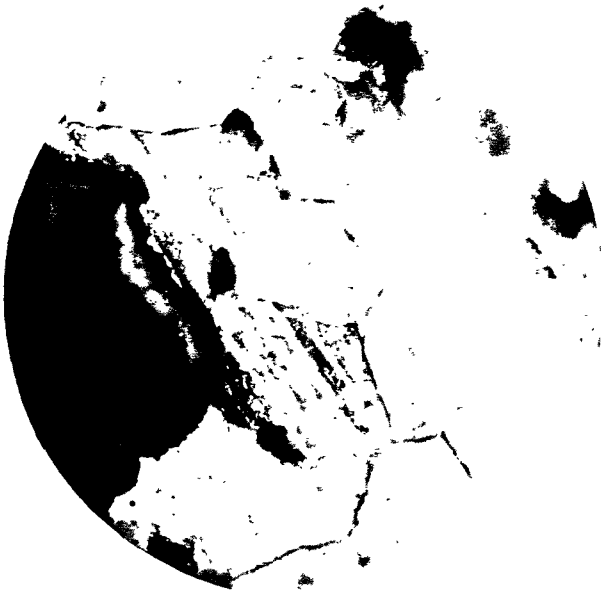


FIG. 1.—Roman Iron from Corstopitum. Magnified 280 diameters.
Polished and photographed by J. Kerr, November 5, 1909.
(Louis and Dean.)



FIG. 2.—Roman Iron from Corstopitum. Section showing Slag and Ferrite.
Magnified 160 diameters.
(Louis and Dean.)

PLATE III



Roman Iron from Corstopitum. Section showing Ferrite only.
Magnified 160 diameters.
(Louis and Dean.)

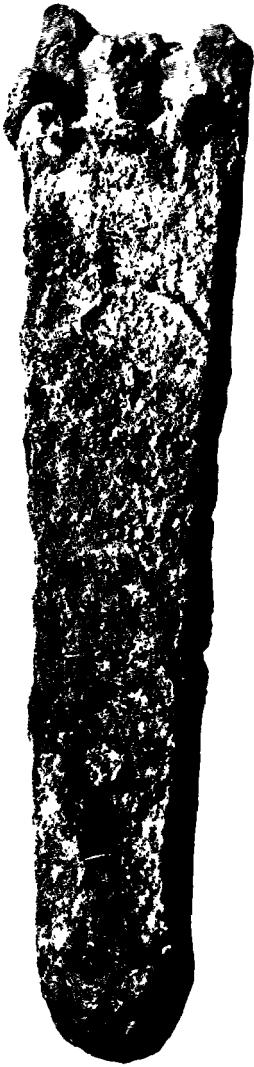


FIG. 1.—Bloom of Roman Iron found at Corstopitum. Length of metallic portion freed from rust, 39 inches; thickness, $7\frac{1}{2}$ inches and $4\frac{1}{2}$ inches. Weight, 3 cwt. 8 lb.



FIG. 2.—Auto-sulphur Print from Specimen previous to etching.
(J. E. Stead)



FIG. 1.



FIG. 2.

Photographs of Drawings showing how the Roman Bloom was built up.
 $\frac{1}{2}$ th natural size. (J. E. Stead.)

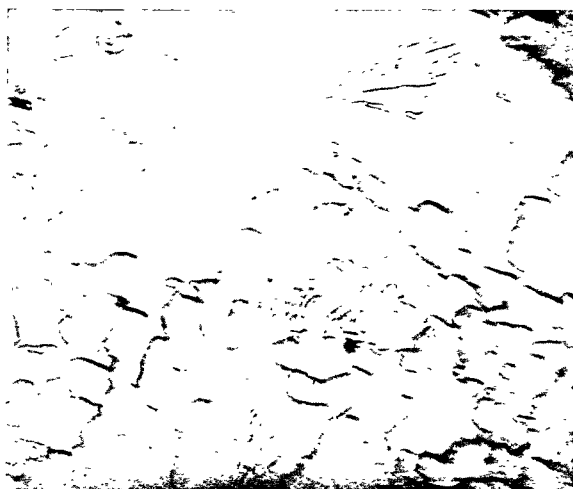


FIG. 1.—Polished only. Cementite is in relief.

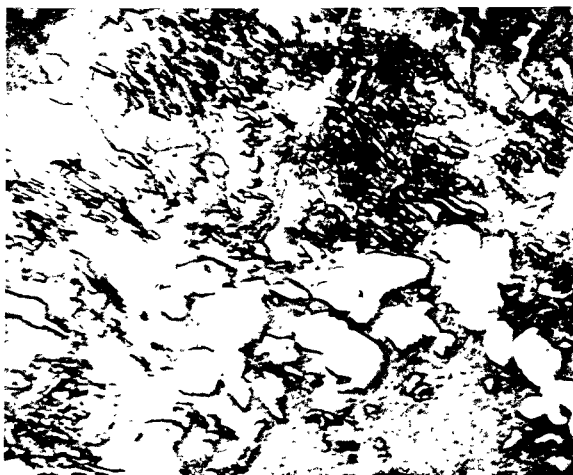


FIG. 2 —Etched with picric acid. The white parts are ferrite, the dark parts sorbite, and the ground mass is ferrite.

Sections from Roman Bloom Steel containing 1.6 per cent. of Carbon, showing evidence of segregation of Fe_3C , and that the last heating of the bloom was prolonged between 700° and 800° C.

(J. E. Stead.)

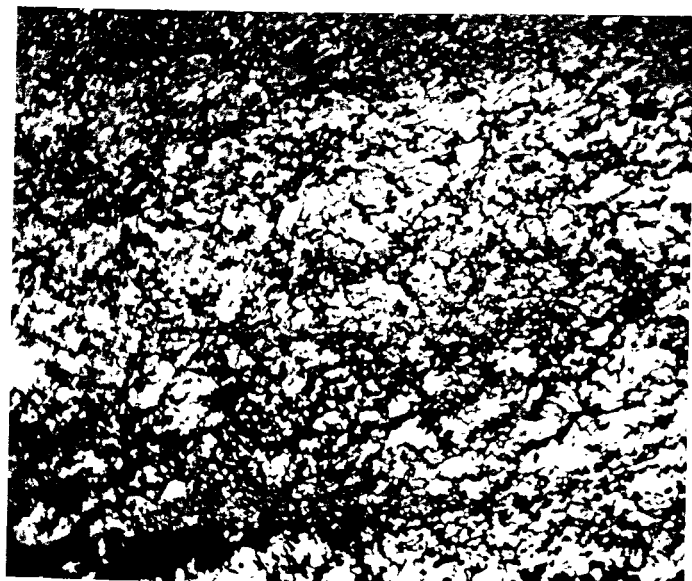


FIG. 2. - Section, natural size, from portion of Bloom marked A in Plate IV; Fig. 2, where enclosed slag is excessive.
(J. E. Stead.)



FIG. 1. - Section, natural size, from portion of Bloom marked B in Plate IV; Fig. 2, showing that included slag is almost completely absent.
(J. E. Stead.)



Remains of Furnace in which the Bloom was found



Bartholomew, Ed.

- | | | |
|--------------------|-----------------------|------------------|
| 1. Cor-stopitum. | 5. The Belling | 9. Whittington. |
| 2. Ridsdale | 6. Chesterholm. | 10. Gossett, &c. |
| 3. Hare-haw | 7. Chesterwood | 11. Wylam. |
| 4. Bellingham Toll | 8. Apperly and Hedley | 12. Brinkburn. |

The principal outcrops of iron ore are shown in red

xxx Many outcrops of clay ironstone on these moors, and remains of ancient slag heaps.

Map showing position of Cor-stopitum and best known Iron Ore Outcrops in the surrounding country.
After G. A. I. Let us, P. Sc., I. G. S.

DISCUSSION.

Sir HUGH BELL, Bart, Past-President, in introducing the paper, said that the actual ingot, or half of it, was in the room, the ingot having been cut in two. While he had been investigating the subject of the paper there had been some correspondence upon the subject with those interested in questions connected with the early manufacture of iron, and he hoped that some of that correspondence would appear as part of the Proceedings.

CORRESPONDENCE.

Professor HENRY LOUIS (Newcastle) wrote that he had one or two remarks to make with regard to the paper, in which he was much interested. The point which Sir Hugh Bell had raised as to whether the iron was made by the indirect or the direct process was one upon which everybody did not agree, but he, personally, was quite in agreement with the view of Sir Hugh Bell, which had been his own view from the beginning—that the iron was made by the direct process. There was no real evidence that the Romans knew cast iron, except as produced by accident now and then. Iron (and steel) was the material most naturally used and sought after throughout the ages, because it was a good fighting material, but cast iron was not known until well on in the sixteenth century. The well-known author Agricola, writing about the middle of the sixteenth century, described the process of making steel by immersing wrought iron in a bath of cast iron, but the requisite cast iron had to be produced by a very special and round-about process. Cast iron was not produced in the ordinary way of making iron at all, and there was very little doubt that up to about that period that material had only been produced by accident. It was only the gradual increase in the height of the furnace used for making wrought iron that led to the manufacture of pig iron.

He happened to have seen a great deal of the direct manufacture of wrought iron, which had always been a matter of considerable interest to him. He had seen the process by which it was manufactured in small furnaces in the Central Provinces of India, and had studied its manufacture direct from magnetic ore at Lake Champlain, N.Y., which was probably the last district in which wrought iron was made direct from the ore in a civilised country on a manufacturing scale. There appeared to be several different types of furnace in use in various parts of India, and possibly a brief description of the process that he had seen in Jubbulpoor might be of interest. The furnace was built of dried clay along the edge of a trench some 3 feet deep. It stood about 3 feet high above the trench; the bottom of the hearth was about a foot above the bottom of the trench, so that the furnace was about 5 feet high inside; it was about 10 inches

square at the mouth, but widened out to about double that size at the hearth. The back and side walls were about 2 feet thick, but the front wall, facing the trench, was only a couple of inches in thickness. Through that passed a couple of tuyeres, made of dried clay, about 2 feet long, pierced with a 2-inch hole. The blast was supplied by

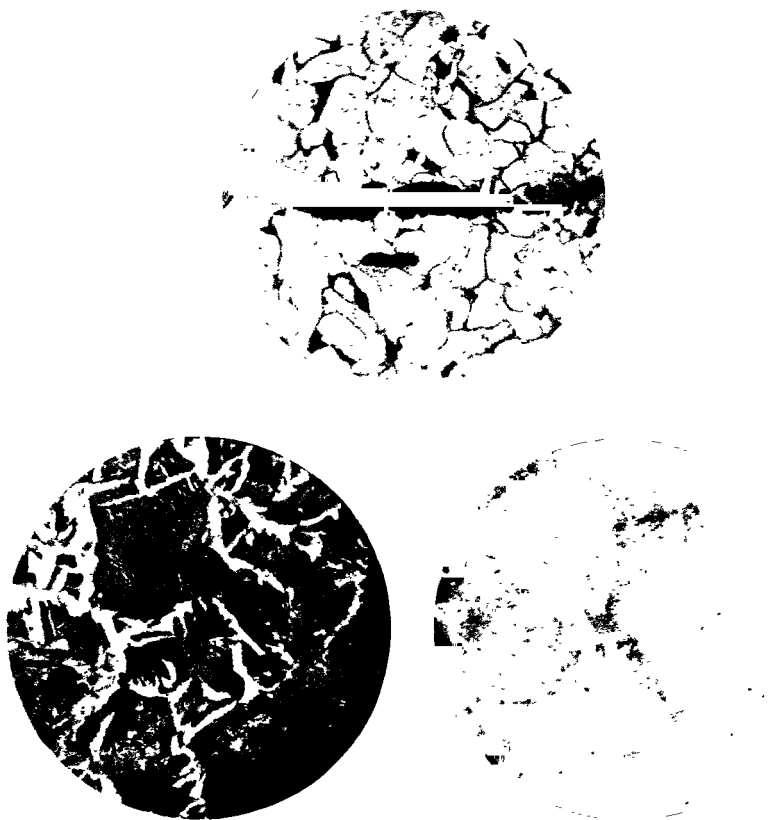


FIG. 1.—Photomicrographs of Native-made Indian Iron. Average carbon content = 0.44 per cent. The three photographs were of different fields of the same section, which was about $\frac{1}{4}$ inch square. Magnified 290 diameters. Illumination—Vertical.

means of a pair of circular goat-skin bellows worked by hand; a roof of branches and leaves was built over the bellows to screen them (and the man blowing them) from sparks. The furnace was filled with charcoal, and, after that had been ignited, small baskets of ore and charcoal were thrown on alternately at intervals of about half an hour. After some ten or twelve hours' work, the thin wall was broken down, and a bloom of some 70 lbs. weight was got out. That rough bloom was cut

into pieces, heated up in a primitive forge and hammered into flat cakes, in which form it was sold. That description might be of interest in view also of Sir Robert Hadfield's paper. There was one point which Sir Robert mentioned in his paper, indicating that the Indian metallurgists were acquainted with cementation, as to which he was rather doubtful. It was quite clear that they knew how to make steely iron, and could weld such steel to ordinary iron, so that they were able in that way to obtain effects similar to cementation, although it was doubtful that they understood cementation as it was understood at the present day. A point of great interest with regard to direct-made iron was its great variability in structure, as shown, for instance, in the immense difference between Dr. Stead's micro-sections and his own. He submitted three photomicrographs (Fig. 1) taken from a small piece of direct-made Indian iron, not more than a $\frac{1}{4}$ inch square, one section showing pure ferrite, another ferrite and pearlite, and the third almost entirely pearlite. He would point out that that rapid variability in the carbon contents was one of the most notable characteristics of direct-made iron. Another noticeable point in those photomicrographs of direct-made iron was that the ferrite crystals were rather more widely separated from each other than in ordinary wrought iron or puddled iron; it was, he thought, doubtful whether that was due to the method of manufacture or to the lesser amount of work which had been put upon such direct-made iron as compared with iron made by other processes. He had, however, no doubt at all about the method of manufacture of the Roman bloom which was the subject of Sir Hugh Bell's paper. It seemed to be quite clear that it was made direct from ore, and probably from the iron ores of the coal-measures of the district in which it was found. As to what use it was intended for, that was entirely a matter of conjecture.

Mr. GEORGE TURNER (Glasgow) wrote that he was at a loss to understand why the word "Roman" had come to be applied to the bloom referred to. The thickness of the overgrowth of soil and vegetation was not stated; nor were there any of the accompanying elements of a kind which belonged to the Roman period of occupancy of Great Britain. The Romans were certainly great military smiths, working in both bronze and iron, which the remains of their camps proved. They were not, however, iron-makers as the Celts everywhere were, according to the Roman writers themselves, which was confirmed by Celtic tradition, and the latter further attested by the numerous iron slag heaps bearing Celtic names, with evidence of the process employed, which was without doubt non-Roman. The presence of Roman coins in slag heaps, which had been of frequent occurrence in England, merely proved the operations to be concurrent with the Roman occupation. The writings of Mr. George Tate clearly showed that the most ancient iron slags of Northumberland and elsewhere were of Celtic origin. Much information on the early

connection of the Celts with the iron industry could be found in Professor Ridgeway's "Early Age of Greece," vol. i.

In his (Mr. Turner's) opinion, the bloom under consideration belonged to the close of the 13th or the beginning of the 14th century, when the iron industry was pre-eminently active at Corbridge. Possibly it was intended to be forged into a water-mill spindle, as water power was then being extensively applied; the operations may have been precipitately abandoned at the time of one of the Scottish raids. The remarks made by Professor Henry Louis on the Corbridge bloom seem to accord with the practice at that time (13th and 14th century)

Towards the close of the 13th century¹ iron must have been manufactured in considerable quantities in the North-Midland part of the county of Northumberland, as in 1298 and 1299 large purchases were effected at Corbridge Fair, and sent to Newcastle and Carlisle, by the English government for expeditions against the Lowland Scots, who were then making frequent incursions into England in search of that metal, and devastating the country along their line of march. About five years later iron was shipped from Berwick-on-Tweed, and in 1315 the government of the day drew from Newcastle the ironwork necessary for their military operations in Scotland. Owing to the frequency of those inroads, and the extent of the havoc wrought by the Scots, the making of iron in the uplands of the county probably ceased altogether in 1318, as the King then ordered purchases of iron and steel to be made in London for the munition of Berwick Castle.²

Professor F. HAVERFIELD (Oxford), who had been closely connected with the Corbridge excavations, wrote regretting his inability to be present. He thought the account of the use of the "nozzle," shown in Fig. 2, p. 126, was almost certainly wrong. The "nozzles" were found, not in connection with the kiln, but in connection with an adjacent bath-building, and wholly or almost wholly inside it and along the lines of its walls. Similar nozzles had been found elsewhere, in places where there was no kiln known, nor any iron, but where there was a bath-house, and they had occurred in each case in definite connection with that, for example, at Binchester in Co. Durham, and at Niederberg, Vielbrunn, and Mohn in Germany. At Niederberg one nozzle was found with a long nail in it. According to German writers, they were employed with similar long nails to hold an outer skin of tiles a little distance from the actual wall; the hot air could then rise between the wall and the outer skin, and warm the room. If that view were correct, those "nozzles" assisted to provide just the same channels for hot air as were provided elsewhere by box-tiles, or by the so-called *tegular hamatur*, and had nothing to do with the

¹ "The Iron Industry of England, Historically and Topographically considered," by George Turner, in a series of seven papers, *The Ironmonger*, 22nd Aug. and 26th Dec. 1908; 27th March and 7th Aug. 1909; 27th May, 24th June, and 23rd Sept. 1911.

² See also "The Ancient Iron Industry of Stirlingshire and Neighbourhoods," pp. 6 to 8, in *Transactions of Stirling Natural History and Archaeological Society*, 1910-11.

furnace. For the rest, he was inclined (so far as he was able to judge) to agree with the views of Professor Louis, and he desired to express his thanks further to Sir Hugh Bell and Dr. Stead for all the trouble which they had taken in examining the "bloom" and clearing up its character. In reference to Mr. Turner's suggestion that the bloom was not Roman at all, but dated from mediæval iron-working at Corbridge, he desired to point out (*a*) that it had been found amidst purely Roman objects, (*b*) that no mediæval remains had occurred anywhere on the site of Corstopitum, and (*c*) that he was assured by the latest historian of Corbridge, Mr. H. H. E. Craster, that no iron was worked in Corbridge in the Middle Ages, though pieces might have been bought and sold at Stagshaw Bank Fair, to which all Northumberland used to resort.

Dr. J. E. STEAD, F.R.S., Vice-President, wrote that one point of interest in the analysis of the cinder taken from the upper part of the bloom was the large amount of chlorine present. The alkalies were not in sufficient quantity to combine with that chlorine, and he (Dr. Stead) was forced to conclude that basic oxy-chloride was present: how it got there he could not conceive. With regard to the question as to whether the Romans were acquainted with the process of carburising steel by cementation, it was known that they did manufacture steel, and that it was almost certain that the carbon must have entered the iron by cementation. It was doubtful whether they practised the process as conducted in modern times, but it was easy to conceive how pieces of iron could be carburised by embedding them in the heart of a large charcoal fire and maintaining them at a high temperature by using blast insufficiently strong to penetrate to the centre of the hearth. The combustion of the charcoal near the walls of the furnace in such case would maintain the iron and charcoal at a sufficiently high temperature to admit of any degree of carburisation required. The pieces of steel welded in the bloom, illustrated on Plate V. in half tone, in his opinion must have undoubtedly been produced in some such way, and, if so, might correctly be described as a cementation process.

Since the reading of the paper, with the assistance of Mr. J. L. Potts of Messrs. J. H. Andrew & Co. Ltd., Sheffield, the planings and sawings which were produced on cutting and planing the bloom had been welded together and forged into a bar. The bar was passed through a cementation furnace and carburised to the extent of about $1\frac{1}{4}$ per cent. carbon. It was then forged down, and about twenty-five penknives were made from the steel by Mr. Joseph Westby of Sheffield, the blades being stamped with the word "Corstopitum." Those blades were of unique interest, representing as they did—excepting for the small amount of carbon added—material made probably more than 1500 years ago.

SINHALESE IRON AND STEEL OF ANCIENT ORIGIN.

BY SIR ROBERT HADFIELD, F.R.S. (SHEFFIELD).

SECTION A.

INTRODUCTION.

THE use of iron, including in this term the combination of iron and carbon known as steel such as produced by the fusion or cementation processes, has without doubt existed from a time dating back to a very early period in the world's recorded history.

Owing, however, to the avidity of the oxygen present in the air for this metal, it has been most difficult to obtain ancient specimens of iron. We have therefore but little definite evidence regarding its early manufacture and use. It is for this reason the author thought that the present description of some interesting Sinhalese¹ specimens of this nature which came under his notice during a recent tour in the East would be of interest to the members of the Institute.

We who live in this modern Western world are apt to pride ourselves that we have all the knowledge on this subject of metallurgy, but the facts presented in this paper show this assumption to be incorrect. Whilst information available from the East regarding iron of ancient production is fragmentary, yet undoubtedly a comparatively high state of metallurgical art and knowledge must have prevailed, not only centuries but more than a thousand years ago.

The author has taken advantage of the opportunity afforded to make what he hopes will prove an addition to our knowledge, and trusts the information submitted will prove to be of interest.

¹ The term "Sinhalese" is explained as follows by Dr. S. M. Burrows, M.A., in his book, "Buried Cities of Ceylon":—

"In B.C. 543, Wijayo and his Sinhalese followers landed in Ceylon, possibly near the modern Puttalam on the west coast. He is said to have been the discarded son of one of the petty princes in the valley of the Ganges, while the native chronicles explain the name of his race by tracing his paternity to a lion—'Sinha.' "

This is not the first paper which has been read on this subject. One hundred and seventeen years ago—to be exact, on June 11, 1795—Dr. George Pearson, a Fellow of the Royal Society, read a paper entitled “Experiments and Observations to investigate the Nature of a Kind of Steel, manufactured at Bombay, and there called Wootz, with Remarks on the Properties and Composition of the different States of Iron.”

The author is greatly indebted to the Royal Society for permission to make use of Dr. Pearson's paper, as well as of his own paper recently communicated to that Society.

It was the author's good fortune during his recent tour round the world, to visit the Colombo Museum and inspect a set of ancient specimens of iron and steel which were obtained from some of the buried cities of Ceylon. These cities date back from about 500 B.C., and since then have had a more or less continuous history as habitable by human beings; the history of some of them continued up to about 1500 A.D.

This collection, which was formed quite recently and has not been previously known or described, was lighted upon quite by chance, and was the find of an otherwise idle day. It is a fascinating collection of ancient specimens and instruments of iron, and is in many respects absolutely unique. The author met the then Director (April, 1910) of the Museum, Dr. Arthur Willey, F.R.S., and was afforded every facility for examination. Finally, through the kindness of his friend, His Excellency the Governor-General of Ceylon, Sir Henry McCallum, to whom grateful acknowledgment is here made, he was accorded the privilege of having placed at his disposal a few of the specimens for investigation. It seemed to the author that an account of the research carried out on these specimens might form an appropriate sequel to the interesting paper to the Royal Society by Dr. Pearson on “Wootz” steel, a century ago. The matter has been made the subject of special reference in the annual report of Dr. Willey, and much interest has been aroused. The author believes that the research which has been carried out yields information which has not previously been available on the subject of iron and steel specimens of known ancient origin—in fact, he has not been able to find in previous publications

any complete and authentic analyses accompanied by mechanical tests and photomicrographs showing the structure of such material.

Not only does the Colombo Museum contain this large number of interesting specimens of ancient tools and implements of various kinds—some 250 in number (these are shown in Plates X. to XIII. accompanying this paper)—but in another section of its exhibits are shown several swords of more modern date, bearing the dates of the years 1374 and 1416 A.D., with Sinhalese legends inscribed upon them.

To those interested in the metallurgy of iron and steel, this collection of ancient iron and steel specimens appeals as being without doubt the most complete and unique in the world. There is probably nothing at all like or approaching it in any other museum or private collection.

The following is Dr. Willey's description of the specimens sent to the author from the Colombo Museum for the purposes of this research :—

1. Museum specimen, No. 138, steel chisel from Sigiriya, of the fifth century A.D., length 10 inches.
2. Museum specimen, unnumbered, ancient nail (pointed end broken off), $13\frac{1}{2}$ inches long, probably also from Sigiriya, of the same date as the chisel, but the particulars are lost. It is, however, certainly very ancient, and is typical of a special class of implements found in the ruined cities of Ceylon.
3. Native bill-hook or "ketta," just as it came to hand from Dumbara, near Kandy, the headquarters of much mediæval native work.

In this paper it has been attempted to deal only with specimens of iron of undoubted antiquity. With the modern manufacture of Sinhalese and Indian steels, it is undesirable to deal at the present time. It may be mentioned, however, that owing to the kindness of His Excellency the Governor-General of Bombay, Sir George Clarke, a number of specimens of Indian iron and steel, not of ancient origin but made in comparatively recent times, were obtained at considerable trouble and furnished to the author, and are also under examination. If these prove of interest, a report

upon them will be submitted later. The author takes this opportunity of thanking Sir George Clarke, also a number of the Residents in the provinces of Mysore, Gwalior, Hyderabad, and Calcutta, who have been at so much trouble in obtaining these various specimens and furnishing detailed particulars of how they were produced.

With this preface the author will now refer to the causes which led to his own investigations and research. Whilst there is often an impression that the use of iron, including in this term the alloy of iron and carbon known as steel, is a modern development, this is probably incorrect, as without doubt such knowledge really dates back to the earliest stages of tradition. For several reasons, and, notably, owing to the avidity of iron for the oxygen present in the air, it has been difficult to obtain ancient specimens of this material, more particularly in the form of steel. It is for this reason that the Sinhalese specimens in question are so valuable, for there exists but little definite evidence as to the period when iron and steel were first employed by man.

There is a reference in the report of the Director of the Colombo Museum to the fact that iron implements are very liable to rust even in the atmosphere of Ceylon with its constant high temperature, and even after having been cleaned and impregnated with paraffin wax by Krefting's method. Rust preservatives are therefore used in the Museum from time to time as rust appears; the simplest way has been found to give the specimens a coat of the above varnish.

The importance of this subject was recognised by Dr. Willey at the time of the author's visit to Ceylon, and in his report above quoted he expressed the hope that more of the long steel stone-cutting chisels would be found during the course of the Archaeological Survey operations, so that further examination could be made. It was also stated in the report that the ancient Indian method of making steel in clay crucibles seems to be identical with the method thought to have been invented in England in the middle of the eighteenth century.

Another reason which caused the author as a metallurgist to be specially interested in these Sinhalese specimens was

that during his tour in the East he first visited Egypt, and an inspection there of the wonderful works in stone raised questions in his mind as to the method and tools with which these memorials in stone were hewn to shape.

It has been asserted that the Egyptians knew how to harden copper so that it could be made to take and keep a cutting edge under the severe working stresses to which the tool must have been subjected in order to produce the hundreds of thousands of forms now to be seen in the Nile Valley from Cairo to Khartoum or beyond, over a distance of some 2000 miles. Such work must have involved the labours of immense numbers of stone masons, who would require tools. The author is strongly of opinion that no method of hardening copper was then known which would produce tools having a hard cutting edge, or which were at any rate at the same time tough enough to stand the severe impact blows such as stone-cutting work required. Copper alloyed with other elements can be hardened, as was recently evidenced in a paper read by Dr. Rosenhain and Mr. Lantsberry before the Institution of Mechanical Engineers. During the course of the discussion on the paper it was stated that a turning tool had been made which had cut iron. The author is of opinion, however, that such a material made up into chisels, wedges, and the like would be of little value for hewing to shape and finishing the gigantic works in stone of the Egyptians.

It is far more probable that the ancient Egyptians were not only able to make steel for tools of all kinds, but also to cement and harden it, or, if they were not themselves steel workers, they obtained the necessary material and help from the workmen of another nation. There is indeed evidence that such was the case, and the facts available suggest that in the art of steel-making Egypt received assistance from India or China. There are, it is true, but few specimens of iron or steel tools or implements in and from Egypt. There is, however, a scythe of iron in the British Museum; examination shows it to be in such an oxidised condition that it is not possible to say definitely what is the nature of the material, although it is undoubtedly iron. This scythe, which the author has seen and handled, is so thin and

corroded that it would almost fall to pieces unless most carefully dealt with. There is also an important specimen of iron taken from the Great Pyramid. In determining this general question as to the use of steel by the Egyptians it should be remembered that there are several ways of endowing iron with the quality of hardening—that is, after heating and quenching it in water, or other cooling medium. The material ordinarily termed wrought iron can be made to acquire or take up carbon by cementation. This process is still largely carried out in Sheffield principally upon bars which are by these means carburised with required varying percentages of carbon. These bars are chiefly made for the purpose of afterwards being melted into crucibles to produce the highest and purest qualities of steel. Such cemented steel, or “blister” steel, is in some cases directly worked up into tools having cutting edges, and is then termed bar steel. This aspect of the case is referred to because even if ancient specimens of highly carburised steel are not available, it must be remembered that wrought or forged iron itself can be cemented or carburised, or the edges of tools can be so treated.

There is reason to believe that this knowledge, although in a crude form, was possessed by ancient workers in iron. Such methods may probably be regarded to a certain extent as “case-hardening.” In such process the surface of the material to be treated must have been placed in a gaseous medium, or in a medium of charcoal or other pure form of carbon, then heated, and the surface carburised to the desired extent and depth. Such material, when again heated and quenched, would carry a cutting edge.

Somewhat singular to say, this knowledge appears to have been possessed and to be proved in an interesting manner by one of these Sinhalese specimens which the author has examined, namely the chisel (Experiment No. 2252), which is proved to have its edges cemented or carburised. Under the section devoted to the description of these experiments will be found full particulars of this remarkable chisel, together with photomicrographs, analyses, and the results of mechanical and other physical tests.

The other and chief method of producing “cast steel”—

that is, an alloy of metal with carbon varying from about 0·50 to 1·80 per cent., is of course by direct fusion of bar iron, or, in the case of a steely iron made in the manner just referred to, in a closed receptacle or "crucible." To accomplish this required a high technical knowledge, for it is not merely necessary to obtain the requisite quality of bar or melting iron, practically free from or very low in sulphur and phosphorus, but there has also to be solved the equally difficult problem of preparing a receptacle or crucible to withstand handling at the high temperature required to fuse the materials being melted, and also the intense heat to which it is subjected without itself fusing. It is interesting to observe that in the Colombo Museum clay crucibles (of modern manufacture, it is true) can be seen, but apparently the same method has long been known and practised in the East. Therefore our modern belief that such method originated in Europe is probably not correct.

As before mentioned, the specimens in the Colombo Museum were taken from the ruins of some of the buried cities of Ceylon, and in view of the importance of the collection, the author instructed Messrs. Plâté, the excellent photographers in Colombo, to prepare for him the photographs of the specimens which accompany this paper.

The names of the buried cities in question are—Anuradhapura, 437 B.C.–769 A.D.; Polonnaruwa, 769 A.D.–1319 A.D.; and Sigiriya, 479 A.D.

An interesting paper on the ruins of Sigiriya appears in the Royal Asiatic Society's *Proceedings*, vol. viii., 1876.

The articles in each photograph are numbered and accompanied by a tabulated statement describing the specimens, also stating from which of the ruins of the buried cities in Ceylon they were taken. No less than about fifty different articles are comprised, including those for agricultural implements, cutting instruments, tools for building and other trades, warlike implements, and general articles.

Whilst the Sinhalese temples and monuments are of much later date than those of Egypt, nevertheless, in view of the metallurgical knowledge which was evidently possessed at a very early period in India and later in Ceylon, it is quite

clear that the knowledge then prevailing in these matters must have been considerable. There is no evidence that the metallurgy of iron was understood in Egypt; it seems more than likely, therefore, that, as has been suggested by several authorities, aid was obtained by the Egyptians from the Far East—no doubt India or China, whence there was a constant stream of trade and commerce. They were thus enabled to carry out their many wonderful works in stone, including temples, pyramids, statues, obelisks, sarcophagi, sculptured walls, figures, tombs, steles, and the like, many of them prepared from the intensely hard Assouan granite, also red and black granite, quartz, porphyry, limestone and sandstone. Some of the hieroglyphics have been found cut to a depth of no less than 2 inches. To carry out such work would require tools of excellent quality.

As will be seen by the figures in Plates X. to XIII., there are several hundreds of these ancient iron specimens. They comprise large and small chisels, including stone-cutting chisels, about $2\frac{1}{2}$ inches in length and $\frac{1}{2}$ -inch in diameter, axes, adzes, hoes, wedges, scissors, locks, keys, and many other articles. As regards the age of the specimens, Dr. Willey, F.R.S., the then Director of the Colombo Museum, states that this is vouched for by those thoroughly competent to make the statement, and that the specimens are 1200 to 1800 years old. They are in a remarkably good state of preservation, and many of them being quite bulky offer much better scope for examination than anything of the kind the author has ever seen or heard of.

When considering the origin and nature of these specimens, it should be borne in mind that the "Veddhas," the aboriginal hunting caste or hill tribe of Ceylon, were of very poor intellect, and it is extremely doubtful whether the high order of knowledge necessary to produce steel, and particularly steel by the crucible process, could have been possessed by them.

Ceylon is, however, from the ethnological point of view, practically an integral part of India. The distance between the two countries is so small that it is shortly to be spanned by rail. There seem, therefore, good grounds for the assumption that the requisite skill and knowledge required for steel-making probably reached Ceylon from India.

SECTION B.

OPINIONS BY VARIOUS AUTHORITIES WITH REGARD TO THE
SO-CALLED IRON AND BRONZE AGES.

In a most excellent sketch of the history of iron in his "Metallurgy of Iron and Steel" (1864), Dr. John Percy, F.R.S., stated, as the author has already pointed out, that iron is so rapidly corroded and wasted away by the oxygen of the air, even in dry climates, that it is not to be wondered at that only few ancient specimens have remained preserved.

Dr. Percy also believed that from metallurgical considerations it is not unreasonable to suppose that the so-called Age of Iron preceded the Age of Bronze, or, if not, was concurrent. The metal of the latter age required more skill to produce than iron, whose process of production in its simplest forms is not so difficult. As Dr. Percy points out, if a lump of red or brown hæmatite be heated for some time in a charcoal fire, well surrounded by or embedded in the fuel, it will be more or less completely reduced so as to admit of being easily forged at a red heat into a bar of iron.

Singular to say, the author cannot find even one analysis of an ancient iron specimen by Dr. Percy, whose eminence in the metallurgy of iron and steel during the last generation was renowned, thus showing that specimens of such material were indeed *rare æres*. The author therefore believes that the ancient specimens now described for the first time represent an accurate analysis of ancient iron, in this case made about 1400 years ago. They also probably represent the type of material produced at a much earlier date.

Mr. St. John V. Day's "The Prehistoric Use of Iron and Steel," published in 1877, and Beck's *Geschichte des Eisens* (1903), in five volumes, covering no less than about 6000 pages, are both remarkable books on iron and steel in reference to their past history.

Day believes, with Dr. Percy, that the use of iron has a very ancient origin, and preceded the so-called Bronze Age. Day says "that the earliest of substances with which man was acquainted was unquestionably iron and almost certainly

steel; . . . and that this is true whether we look to Egypt, Babylonia, or Proto-Chaldea and Assyria, on the one hand, or China on the other."

Day points out that iron has been discovered in the Great Pyramids, the oldest buildings known to men.

Lepsius, an Egyptologist of the highest rank, says that, "considering the frequent working of granite in large masses, which can be proved near the fourth Manethoic dynasty, it cannot well be doubtful that since that time, and indeed earlier, iron and the hardening of it were known."

Many tablet pictures show workers wielding tools which could not very well be those other than of iron or steel, and Maspéro, in the interesting recent correspondence with Osmond referred to in this paper, admits the wall pictures of Egypt show workers handling tools which were surely of iron or steel.

Dr. Percy therefore seems fully justified when, in writing to Mr. Day, he makes the following important statement:—"I become more and more confirmed in my opinion that archaeologists have been generally mistaken concerning the so-called Iron Age. I am collecting further information on the subject from time to time, and as yet have met with nothing in opposition to the opinion above mentioned."

Professor Max Müller, so Day points out, stated that "in the Homeric times knives, spear points, and armour were still made of copper: and we can hardly doubt that the ancients knew the process of hardening that pliant metal most likely by repeated smelting and immersion in water." The author quite agrees with Day that such a statement on the face of it cannot be correct, for copper is not hardened by immersion or cooling in water, but, on the contrary, it is softened. Moreover, no one has yet been able to harden copper in the manner that iron does when combined with carbon. If such an art had been known, it is difficult to imagine that the knowledge would have been entirely lost; it would have been too valuable. The world has yet to discover a method of hardening copper, in the sense of producing a material which can be compared with hardened steel. Alloys of copper with tin and other elements are well known, but their qualities render

them unsuitable for purposes where iron and steel are used.

In the same manner Day, rightly the author thinks, took the late Right Hon. W. E. Gladstone to task with regard to his laborious investigation of the Homeric epic, when announcing "the age of copper is the first and oldest of the metallic ages, which precedes the general knowledge of the art of fusing metals." Day gives good reasons for his opinion, with which it is not possible adequately to deal here. The reader is referred to Day's most interesting and valuable work, and to a useful paper by the late Secretary of our Institute, Mr. Bennett H. Brough, on "The Early Uses of Iron," in the *Journal of the Iron and Steel Institute*, 1906, No. I. p. 233.

SECTION C.

REMARKS ON THE PAPER COMMUNICATED IN THE YEAR 1795, BY DR. PEARSON, F.R.S., TO THE ROYAL SOCIETY, ON INDIAN WOOTZ STEEL.

Before dealing in detail with the specimens examined in this research, reference may be made to the salient points of Dr. Pearson's paper previously mentioned. The specimens of "Wootz" steel described by him, which were stated as being sent over by Dr. Scott of Bombay in 1795, were not claimed to be of ancient origin, but apparently represented steel which was being manufactured in India at that time—that is, the closing years of the eighteenth century. It is not perhaps surprising that, notwithstanding Dr. Pearson's paper, no record was then or even until much later, made available as to the composition of "Wootz" iron or steel. This is quite natural, as it is only within the last twenty-five or thirty years that really reliable and accurate methods of chemical analysis have been made possible to the worker in this field of metallurgical research. In this connection the author well remembers the fact that about thirty years ago his father one day showed him, as a great achievement, a certified analysis of a specimen of steel. In that analysis, for which a fee of fifteen guineas

had been paid, five elements had been determined, probably most of them not very correctly—at all events as compared with the accuracy possible at the present day. That was but a generation ago. It is now possible, at very small cost, to obtain complete and accurate analysis of the composition of iron and steel, not only of simple types but of the most complex compositions. It is impossible therefore, to withhold our admiration of the work of the chemist, which in a comparatively few years has led to this great advance in methods of analysis, whether as regards accuracy, rapidity, or low cost.

As a proof of this it may be interesting to here mention that the author has been informed by one of the very able directors of Messrs. Krupp, Dr. Ehrensberger, who has done so much to advance metallurgical knowledge in Germany, that in 1910 the total number of analyses carried out in their laboratory was no less than 416,728. His own firm carried out in the same year a total of 39,653 analyses. Therefore, in the metallurgical world there must now be made many millions of analyses in each year. Even but a generation ago such a possibility was hardly dreamt of.

Although the chemical composition of the "Wootz" steel in question was not put on record, Dr. Scott, who forwarded the specimens to Dr. Pearson, describes these as "admitting of a harder temper than anything known in that part of India; that it is employed for covering that part of gunlocks which the flint strikes, that it is used for cutting iron on a lathe, for cutting stones, for chisels, for making files, for saws, and for every purpose where excessive hardness is necessary." Also that it "cannot bear anything beyond a very slight red heat, which makes it work very tediously in the hands of smiths." It is added that it "could not be welded with iron or steel, to which therefore it is only joined by screws and other contrivances." Dr. Scott also pointed out that "when working, if heated above a slight red heat, part of the mass seems to run, and the whole is lost, as if it consisted of metals of different degrees of fusibility." "Working with Wootz is so difficult that it is a separate art from that

of forging iron"; and "the magnetical power in an imperfect degree can be communicated to this substance."

Dr. Pearson further describes the specimens received by him as being in the shape of a round cake of about 5 inches in diameter and 1 inch in thickness, and weighing about 2 lbs. He stated that "under the file I found Wootz much harder than common bar steel not yet hardened, and than Huntsman's cast steel not yet hardened."

This reference to Huntsman's steel, which has been the subject of several papers by the author before the Iron and Steel Institute and other technical bodies, is very interesting, and indicates that the work of Huntsman was well known at that date, 1795. Dr. Pearson's paper contains a table giving the specific gravity of Wootz and several other specimens of steel and iron, in which it was stated that the specific gravity of these Wootz specimens varied from 7.166, quenched while white hot, to 7.647 in the forged condition, and that this compares with a specific gravity for Huntsman's steel of 7.771 in the hardened condition to 7.916 hammered. Reference is also made in the paper to the assistance given in forging Wootz by "that ingenious artist Mr. Stodart." It is not a little flattering to metallurgists to note that an expert worker of steel was mentioned in such terms, the description "artist" occurring several times in the paper. It may be here mentioned that it is probable Dr. Pearson's co-worker was the same Mr. Stodart who many years later assisted Faraday in preparing and investigating a large number of steel alloys. Although there was nothing very definite obtained from the experiments, they are most interesting, and will be found fully described in *Philosophical Transactions*, cxii. p. 253.

Naturally, owing to the then incomplete knowledge of special steels and of analytical methods, the results were incomplete, but nevertheless valuable as pointing the way.

Thus even at that early period the importance of developing steel alloys made an appeal to the master mind of Faraday, although the actual accomplishment of his ideas was deferred for another sixty years. The first systematic presentation of a steel alloy research was probably that dealt with in the

paper presented by the author to the Institution of Civil Engineers in 1888, entitled "Alloys of Manganese and Iron," in which a complete correlation of method of manufacture, composition, analysis, physical properties, and mechanical and electrical tests were set forth.

In the paper referred to by Dr. Pearson will be found an account of an elaborate research as to the ' Effects of Fire and Oxygen Gas Conjointly,' "Experiments with Diluted Nitrous Acid," also with "Diluted Sulphuric Acid." Much time and attention were given to determining the nature of the gas obtained from the Wootz so dissolved. It is very curious to note the exceedingly painstaking character of the attempts made to reach conclusions, which, of course, could not then be verified for want of the requisite scientific and technical knowledge. Probably the chief want was the chemist to whom metallurgists owe so much for the first advance in true and accurate metallurgical knowledge. Dr. Pearson estimated the "quantity of carbon in the Wootz and steel to be nearly equal: and that quantity to be about one-third of the hundredth part, or $\frac{1}{300}$ of the weight of these two substances," whatever may have been meant by that statement. As an illustration of the extraordinary opinions which then found acceptance from men in responsible positions, and who must be assumed to have had the advantage of the best scientific and technical training of the day, Dr. Pearson states that from some of the solutions so obtained he observed there was "a deposition of white matter and formation of green crystals in a liquid." The green crystals were obviously those of sulphate of iron, and the white matter was the siderite of Bergman, which is now believed to be phosphate of iron. It is curious to note, as showing to what lengths investigators of that day were driven for an explanation of the properties of steel, that Dr. Pearson says: "Common steel, which is all made by cementation, is very malleable when white hot, only perhaps because it contains iron which has escaped combination with carbon."

Dr. Pearson concluded by saying that the Wootz steel which he examined must have been made directly from the ore, and that it had never been in the state of wrought iron. The

author refers to this in connection with facts he brings before the Institute with reference to the specimens of ancient steel obtained in Ceylon, which appeared to be rather of the nature of wrought iron than steel, although some of the specimens appear to have been cemented.

SECTION D.

HEATH AND OTHERS ON "INDIAN AND SINHALESE IRON AND STEEL."

As bearing upon this subject of Indian metallurgical knowledge in 1837 and 1839, Mr. J. M. Heath contributed two interesting papers on Indian steel to the Royal Asiatic Society, referred to in the Bibliography accompanying this paper. Although the specimens described by the writer in this paper are not "Wootz" steel, but rather a species of wrought iron, it may be interesting to mention that Mr. Heath says this term "wootz" or "oots" is probably the name for steel in the Guzerattee language in use at Bombay.

Mr. Heath was, it appears, one of the directors of the Indian Iron and Steel Company, but left India to return to England in 1837. This fact is referred to because of Mr. Heath's important connection with the development of steel-making in Sheffield about that time, and a little later, where he introduced the use of black oxide of manganese in steel manufacture. About this discovery of Heath's it will be remembered there was afterwards a famous litigation. The author regrets to say Heath suffered much monetary loss, though no doubt he was largely entitled to the credit of this great improvement, which was the first appreciation of the importance of manganese in steel manufacture.

Heath, in the two papers read before the Royal Asiatic Society in 1837 and 1839 with regard to Indian steel, offered much interesting information. The author's views entirely coincide with those expressed by Heath nearly three-quarters of a century ago, namely, that the great works of stone in Egypt were undoubtedly carried out by means of iron and steel tools.

Heath's remarks are so interesting that the author quotes them in full as follows:—

“The antiquity of the Indian process is no less astonishing than its ingenuity. We can hardly doubt that the tools with which the Egyptians covered their obelisks and temples of porphyry and syenite with hieroglyphics were made of Indian steel. There is no evidence to show that any of the nations of antiquity besides the Hindoos were acquainted with the art of making steel. The references which occur in the Greek and Latin writers on this subject served only to better their ignorance of it: they were acquainted with the qualities and familiar with the use of steel, but they appear to have been altogether ignorant of the mode in which it was prepared from iron. The edges of cutting instruments of the ancients were all formed of alloys of copper and tin, and we are certain that tools of such an alloy could not have been employed in sculpturing porphyry and syenite.

“Quintus Curtius mentioned that a present of steel was made to Alexander of Macedon by Porus, an Indian chief whose country he had invaded. We can hardly believe that a matter of about 30 lbs. weight of steel would have been considered a present worthy of acceptance of the conqueror of the world had the manufacture of that substance been practised by any of the nations of the West in the days of Alexander.

“In view of the maritime intercourse between Egypt and the East, it appears reasonable to conclude that the steel of the South of India found its way by these routes from the country of Porus, to the nations of Europe and Egypt.”

Heath states, therefore, that “the claims of India to a discovery which has exercised more influence upon the arts conducing to civilisation and the manufacturing industry than any other within the whole range of human invention is altogether unquestioned.”

In his papers, Heath also points out that Dr. Buchanan's “Travels in the South of India,” published in 1807, contains very minute and correct accounts of the native process of smelting iron and making it into steel, this process probably representing practice handed down from previous ages. The book is illustrated by engravings.

Further reference is made to Dr. Heyn's "Tracts on India," published in 1814. This book also contains an account of these processes, together with a very interesting letter from Mr. Stodart upon the quality of Indian steel.

Without doubt, therefore, the processes of making iron and steel have been used in India for many thousands of years. Probably the ancient specimens seen by the author at Colombo were not produced by the crucible process, but that the crucible process has been used in Ceylon for a long period of time may be taken as established.

This would also carry with it the proof that while the Huntsman process was novel as regards application in Great Britain, and of course worked out on a more practical and commercial system than the methods of the East, yet it was, after all, only a development of methods, or an independent comparatively modern discovery of methods, long employed in India. It may, therefore, easily have been the case that the ancient Egyptians were familiar with Indian iron and steel, and either imported the material or obtained the services of Indian workers in metals to produce the necessary material for the tools employed on the great stone monuments. There are those who think the Egyptians obtained help in the metallurgy of iron and steel from China, and in some cases from nearer home, Assyria. The chain of evidence at least appears to be complete, that the knowledge of how to produce and work iron and steel had been acquired in times of antiquity. Heath, therefore, probably rightly claims in his paper referred to that the Hindoos had been familiar with the manufacture of steel from time immemorial, and he held the same opinion as the author that the stone works of Egypt could only have been carried out by tools of iron, probably of cemented or hardened steel.

Other evidence of the knowledge of iron possessed by the ancients may be cited. Dr. Ananda K. Coomaraswamy, D.Sc., who was, until a few years ago, the principal mineral surveyor in Ceylon, has written a valuable and interesting book on "Medieval Sinhalese Art." In this work he deals, amongst other matters, with metal work—iron, brass, copper, and

bronze, gold and silver, jewellery. He states that the knowledge of iron is of great antiquity in India. Its use was certainly well known in the Vedic period, and it is constantly mentioned in Vedic literature. There is also abundant evidence that the ancient Hindoos were not only skilled in manufacturing steel and iron, but in working these products, and in tempering steel. It is claimed, indeed, that Damascus blades were fashioned from Indian iron. The word "Ondanique" of Marco Polo's travels referred originally, as Colonel Yule has shown, to Indian steel, the word being a corruption of the Persian "Hundwaniy." The same word found its way into Spanish, in the shapes of *alhinde* and *alfinde*, first with the meaning of steel, and then of a steel mirror, and finally of the metal foil of a glass mirror. The ondanique of Kirman, which Marco Polo mentions, was so called from its comparative excellence, and the swords of Kirman were eagerly sought after, in the fifteenth and sixteenth centuries, by the Turks, who gave great prices for them. Arrian mentions steel as imported into the Abyssinian ports; and Salmasius mentions that among the surviving Greek treatises was one "On the Tempering of Indian Steel."

The knowledge here recorded must have filtered through from India to Ceylon.

Dr. Coomaraswamy, in the work above-mentioned, gives a very interesting summary and various evidences of ancient Sinhalese iron and steel manufacture. The book also contains an analysis of the hæmatite iron ore deposits, and a description of the method of iron smelting, including an excellent account of the Sinhalese method of making crucible cast steel. The author has personally seen in the Colombo Museum the clay crucible of modern origin made by the Sinhalese.

The manufacture of this crucible cast steel by the Sinhalese is now, however, almost an extinct industry, a fact due to the operation of economic laws, as steel can be imported from Europe more cheaply than it can be manufactured locally. From the standpoint of the history of the industry, the evidence produced on the subject of Indian and Sinhalese crucible working is of great interest. Sinhalese steel is discussed by Dr. Coomaraswamy, and his description of researches on the

subject is accompanied by six most interesting photographs illustrating the manufacture of Sinhalese iron and steel. The photographs include an iron-smelting furnace, general view; iron-smelting furnace, bellows; furnace at work: the bellows blower; steel furnace at work, and removing crucibles from steel furnace. These photographs form an excellent addition to our knowledge of the subject. For reasons previously stated, it is obvious that the production of the crucibles themselves called for the possession of a high order of knowledge, and as it is probable that this method has been in operation for several centuries, another proof is afforded that production of steel by the crucible process was not originated in England. It will be interesting for the purposes of comparison to give the composition of a modern Sinhalese crucible steel, as this entirely differs from the material described by the author, which is really wrought iron.

A sample of such steel has been analysed at the Imperial Institute. The following was the composition of the steel:—

	Per Cent.
Carbon	1.97
Silicon	0.07
Sulphur	0.07
Phosphorus	0.02
Manganese	0.07
Iron	97.77

This specimen is referred to in *Colonial Reports*, p. 33; *Miscellaneous*, No. 37, Ceylon; *Report on the Results of the Mineral Survey in 1904-5*, by Professor W. R. Dunstan, M.A., LL.D., F.R.S., Director of the Imperial Institute.

Dr. Coomaraswamy says that iron-smelting is still carried on at Hatarabäge, near Balangoda, by men of low caste. The ore used is generally the nodular hæmatite or limonite, which arises as a decomposition product of the country rocks, and is widely distributed in small quantities. Before smelting, the ore is broken into small pieces, and roasted to drive off the water. The following is a typical analysis: silica, 9.14 per cent.; alumina, 9.85 per cent.; ferric oxide, 72.39 per cent.; ferrous oxide, 0.22 per cent.; moisture, 8.40 per cent.; sulphur, nil; phosphoric anhydride, 0.05 per cent. (phosphorus, 0.022 per cent.) Steel is made from the iron thus obtained, and

though the industry is no longer carried on, there survived at Alutmuvara, near Balangoda, two very old men who had been accustomed to prepare steel, and did so in order that Dr. Coomaraswamy might study the process and take photographs. Specimens of steel and crucibles then prepared are now in the Colombo Museum.

Mr. Henry Parker, F.G.S., in a contribution to the Royal Asiatic Society (reported in the *Journal* of the Ceylon Branch of that Society, vol. viii., No. 27, 1884, p. 39) deals with discoveries at Tissamaharama. In this contribution he refers to jumpers or chisels, and mentions a stone-cutter's tool, 5 inches long, made of three-quarters iron and steel, with an edge 1·3 inch long.

Parker's discoveries also included part of an iron wedge, a small broken iron trowel, and two pieces of a long bar of round iron. Most of the chisels, particularly the carpenter's tool, belonged to the oldest series of remains. He adds: "From the large number of nodules of kidney iron met with during the Ceylon excavations, it is to be presumed that the iron used for making the axes and other tools was smelted on the spot, probably by the smiths themselves. The iron is so nearly pure that this would present no difficulty, and the nodules could be picked out of the underlying decomposed gneiss or gravel, which is extremely ferruginous."

Parker states that the Kings of Ceylon reigned from Wijaya, 543 B.C., onwards.

SECTION E.

DELHI AND DHĀR PILLARS IN INDIA.

One of the most notable ancient specimens of iron is the famous Pillar of Delhi,¹ which is not the less interesting when we find it is stated that the city itself, "Imperial Delhi, the capital of all India," as Sir Alexander Cunningham in 1864 termed it, owed its name to this pillar. In the light of recent political events, this prophetic utterance is now an

¹ The author has been in communication with Mr. J. H. Marshall, C.M.G., M.A., C.I.E., the Director General of Archaeology in India, who hopes that it may be possible to furnish the author with specimens of material from the pillar itself, for research examination.

actually accomplished fact, for on December 12, 1911, Delhi was made the capital of our great Indian Empire. We have also this remarkable chain of circumstances. Delhi took its name from the very Pillar now described, the Hindoo term being "Dhelli," or unstable, as explained later on. At Delhi King George V., the first English monarch to be present in person, has been proclaimed Emperor in Dhurbar, and finally, Delhi is now the seat and actual 'Capital of all India.'

Ancient associations, historical and legendary, combine to invest Delhi with exceptional dignity in the eyes of both Hindoo and Mohammedan Indians.

In the official Government despatches of last year, it was stated that "Delhi is still a name to conjure with; it is intimately associated in the minds of the Hindoos with sacred legends which go back even beyond the dawn of history."

As shown in this paper, seeing that Delhi itself takes its name from the Iron Pillar, and that it is now the capital of our Indian Empire, with its three hundred millions of inhabitants, this particular article of iron is of more than ordinary interest to the members of our Institute. In view of its importance, what follows may therefore be of interest. There was formerly a plaster cast or model of it in the Victoria and Albert Museum in 1873. The author spent some time in trying to find this at South Kensington, but finally discovered that it was unfortunately destroyed during a fire in 1885, and has never been replaced.

In the *Archæological Survey of India*, p. 169 (four reports made during the years 1862-1865), Sir Alexander Cunningham, C.S.I., &c., states that one of the most curious monuments in India is the iron pillar at Delhi. Whilst there are many large works of ancient times in metal for example the Colossus of Rhodes, the gigantic statues of the Buddhists, and others, these were of brass or copper, all of them hollow and built up of pieces riveted together, whereas the Pillar of Delhi is a solid shaft of wrought iron, upwards of 16 inches in diameter and 22 feet in length, welded together, although the welding is not altogether perfect. In any case, it was a very creditable piece of work for a metallurgist of at least 1600 years ago. At one time, owing to its peculiar colour or hue, it was thought

to be of "mixed metal" or even bronze, this belief probably arising from the curious yellow appearance of the upper part of the shaft, which Cunningham says he himself observed.

He adds that he obtained a small fragment from the rough lower part of the pillar, which was submitted to Dr. Murray Thompson of the College at Roorkee for analysis. who informed him that the metal was "pure malleable iron of 7.66 specific gravity." Practically pure iron (99.87 per cent. iron) has a specific gravity of 7.8477. Therefore, the material of this pillar could not have been pure. Probably it was a somewhat inferior type of wrought iron permeated with slag, and high in phosphorus, like the Sinhalese specimens described by the author in this paper. Pure iron, having the specific gravity mentioned, would weigh 490 lbs. per cubic foot; the Delhi Pillar, with 7.66 specific gravity, would weigh 477 lbs. per cubic foot.

Cunningham points out that, in true Eastern language and hyperbole, the inscription upon the pillar says that "The pillar is called the arm of fame of Raja Dhang, and the letters cut upon it are equal to the deep cuts inflicted upon his enemies by his sword writing his immortal fame."

The actual date of its first appearance is probably about A.D. 300. According to tradition, this pillar was erected by "Bilan Deo," or Anang Pal the founder of the Tomara dynasty, who was assured by a learned Brahmin that the foot of the pillar had been driven so deep into the ground that it rested on the head of Vasuki, King of the Serpents, who supports the earth. But the Rajah doubted the truth of the Brahmin's statement, ordered the pillar to be dug up, when the foot of it was found to be wet with the blood of the Serpents' King, whose head it had pierced. Regretting his unbelief, the iron pillar was again raised but owing to the king's former incredulity, every plan now failed in fixing it firmly, and in spite of all his efforts it still remained loose in the ground. This is said to be the origin of the name of the ancient city of Dhili, which signifies "unstable."

The Committee of the Iron and Steel Institute, in about the third year after its formation (1872, Vol. II. p. 156), made some special inquiries with regard to this pillar. It appears that Lieutenant Spratt, of the Royal Engineers, then

stationed at Delhi. stated the height of the column above the ground to be 24 feet, and the depth below ground 3 feet. He said that the column or pillar ends in a bulb like an onion, which is held in place by eight short thick rods of iron, on which it rests, and which at their lower extremity are let into blocks of stone, in which they are secured by lead. The iron of which the pillar is made seems to have been originally in blooms of about 80 lbs. weight each.

An excellent paper by Mr. Vincent A. Smith, M.R.A.S., Indian Civil Service, 'On the Iron Pillar at Delhi (Mihrauli), and the Emperor Candra (Chandra),' appeared in the Royal Asiatic Society's *Proceedings* of 1897.

There are several important inscriptions upon the pillar, a full translation of which appears in Smith's paper above mentioned. These, notwithstanding the long exposure to wind and rain, are reported to be quite clear and sharp, as if no alteration had taken place since the pillar was first made and erected.

It is stated that these iron pillars were probably used owing to the belief in the special power of this metal to counteract demoniacal influence.

Miss Gordon Cumming, in her book "In the Himalayas and on the Indian Plains," says: "I must first tell you about an extraordinary iron pillar, which stands near the base of the Kootub, and to which the city owes its modern name. It stands 22 feet above ground; some have declared its base is 26 feet below ground; others maintain it only extends a few feet, and terminates in a bulb like a turnip." The latter was later on found to be correct, the exact dimensions of the pillar being—total length, 23 feet 8 inches, of which 22 feet are above and only 20 inches below ground; the upper diameter is $12\frac{1}{2}$ inches, the lower diameter $16\frac{1}{2}$ inches; the total weight is about 6 tons.

Sir Alexander Cunningham's statement that the length was not less than 60 feet was apparently based upon incorrect data.

Miss Cumming goes on to say: "It is wrought like our finest metal, and shows no symptoms of rust, though it has stood here for many centuries. It bears an inscription in

Sanscrit, describing it as the 'triumphal pillar of Rajah Dhava. A.D. 310, who wrote his immortal fame with his sword.' This, however, is the only record extant of his deeds. There are several other inscriptions on the pillar, but of more modern date.

"The Brahmin tradition is, that this pillar was erected in the sixth century, after the stars had pointed out the auspicious moment. It went so deep that it pierced the head of the serpent god Schesnag, who supports the earth. The priests told the Rajah that thus his kingdom should endure for ever. But, like a child gardening, he could not be satisfied till he dug it up again, just to see if it were so, and sure enough the end was covered with blood. Then the priests told him that his dynasty would soon pass away. He planted the pillar again, but the serpent eluded his touch, and the pillar was thenceforth unsteady. So the priests called the name of the place Dhilli, that is, 'unstable,' and prophesied all manner of evil concerning the Rajah, who shortly afterwards was killed, and his kingdom seized by the Mohammedans, and since then no Hindoo has ever reigned in Delhi.

"Nevertheless, the pillar is now firm as a rock, and has even resisted the cannon of Nadir Shah, who purposely fired against it. The marks of the cannon balls are clear enough. Hindoos believe that so long as this column stands, the kingdom has not finally passed from them."

The author has been able to obtain several excellent photographs of the pillar, one of which is shown in Plate XIV. In a photograph taken many years ago, no stone base or pedestal appears, moreover the stones in the neighbourhood of the pillar have been disturbed. This no doubt was caused by those who excavated to see the depth of the pillar below the surface of the ground. This, it appears, was carried out in 1871 by Mr. Beglar. The photograph shows an interesting group of natives examining the pillar. The stone base appears to have afterwards been put in order.

The iron pillar at Dhār or Dhārā (the ancient capital of Malava, and thirty-three miles west of Indor), which was described by Mr. Smith in a paper to the Royal Asiatic

Society in 1898. had a total length of no less than 42 feet. This is specially interesting owing to its extraordinary length. The three existing pieces measure 24 feet, 12 feet, and 6 feet in length, aggregating 42 feet, in addition to a missing fragment, so that if these figures are correct, the column is approximately double the height of the Delhi pillar.

Mr. Smith rightly says: "Whilst we marvel at the skill shown by the ancient artificers in forging the great mass of the Delhi pillar, we must give a still greater measure of admiration to the forgotten craftsmen who dealt so successfully in producing the still more ponderous iron mass of the Dhār pillar monument with its total length of 42 feet, which, like the pillar at Delhi, is of the Gupta period, or about the year 321 of our Christian era."

There are also in existence in India several very large iron girders at Puri, ornamental iron gates of ancient origin at Somnali, and a wrought-iron gun, said to be 24 feet in length, at Nuwiri.

The author has given a detailed description of these two pillars, as they form the only known ancient large masses of iron in the world, so that they are indeed remarkable. But little more than a generation has elapsed since objects of this size and weight were made possible, even in our time.

SECTION F.

REMARKS BY MESSRS. OSMOND AND MASPÉRO.

The author has shown elsewhere in this paper that the ancient specimens now examined cannot be termed "steel"—that is, in the true sense of the word. They are practically wrought iron, though, as evidenced in the chisel, there is distinct proof that the edges of this specimen have been submitted to a carburising or cementation process of some kind. In this sense, therefore, the chisel may be termed "steel"—at any rate as regards such edges.

Moreover, if the art of cementing or steelifying articles of iron was known and understood, then with such knowledge

it would be quite possible to produce tools possessing excellent qualities, as the cutting edges could then be hardened by water quenching. If this was so, as appears to be the case, then we can readily understand how the works of stone were executed in Egypt.

Whilst upon this point, reference may be made to some interesting correspondence the author has had with Mr. F. Osmond, the eminent French metallurgist. Some time ago the author asked Mr. Osmond if he knew of any specimens of ancient iron and steel in existence, and also whether he knew of any evidence in France as to the ancient Egyptians using iron and steel tools. He was however, unable to point to such evidence, but made some inquiries in other directions, with the following result.

These remarks by Mr. Osmond appear to be worthy of giving in full, because they have most important bearing upon the question of the use of iron and steel by the ancient Egyptians. Moreover, they probably prove that the nature of the material used by the Egyptians was iron of similar quality to that found in the ancient Sinhalese specimens obtained from the Colombo Museum, and upon which the present research has been carried out.

Mr. Osmond communicated with the well-known Egyptologist Mr. Maspéro in Egypt, that in reference to a note he (Mr. Osmond) had presented to the Academy on bronze work of prehistoric times, he had been told that during a certain conversation at a personal meeting between Mr. Maspéro, when he was in Paris, and Mr. Berthelot, that he (Mr. Maspéro) had then said that antique paintings or drawings existed, and that these showed each stone-cutter had assistants at his side, whose business it was to repair or sharpen his tools. From this it appeared that possibly tempered steel was not then in use, and that tools were employed made of iron or bronze.

Mr. Osmond then pointed out to Mr. Maspéro that he had received reproductions of paintings extracted from *Monuments de l'Égypte et de la Nubie d'après les dessins exécutés sur les lieux sous la direction de Champollion le jeune* (Paris, 1845, Firmin Didot) which he thought showed that there

were sculptors and stone-cutters who did not appear to have assistants to repair their tools.

Mr. Osmond asked the following questions:—

“Where are the originals showing the stone-cutters with assistants? If there are any reproductions, where can they be found? Are the paintings or drawings showing the stone-cutters with assistants anterior to those reproduced by Champollion? If this were the case it might be possible to fix the date of the introduction of tempered steel into Egypt.

“I have been induced to investigate these questions by my friend Sir Robert Hadfield, Fellow of the Royal Society of London, who has recently obtained some interesting ancient specimens and documents relating to iron and steel production in Ceylon.”

In reply, Mr. Maspéro wrote (March 1911) that he had been unable to answer Mr. Osmond's letter until after his return to Cairo. The following are Mr. Maspéro's own words, which being so interesting are quoted *in extenso*:—

“Je n'ai pu répondre à votre lettre qu'après mon retour au Caire qui a eu lieu il y a quelques jours seulement. Voici brièvement ce qu'il y a à dire sur la matière.

“1. Ce que je racontais à M. Berthelot n'a pas été bien saisi; je parlais d'expériences faites par moi vers 1884-1885 à Louxor. Pour me rendre compte de la technique des sculpteurs égyptiens, j'avais commandé à un faussaire indigène de grande habileté une statue en granit de style égyptien. Assistant à la fabrication, j'ai constaté qu'il employait pour tailler la pierre des pointes en fer doux emmanchées de bois. Il en avait une cinquantaine à sa disposition qu'il emmanchait au fur et à mesure des besoins. Chaque pointe s'émousait après trois ou quatre coups de maillet au plus; il la jetait, en prenait une autre, et un aide mettait au feu, puis battait au marteau les pointes émoussées pour leur rendre leur tête. La statue a été faite—ou plutôt le buste, car elle ne va qu'au milieu de la poitrine—en trois semaines, à force d'user le fer et de le raffermir. À force d'être frappées les pointes devenaient d'une dureté très grande.

“Il n'y a pas dans les monuments de représentations où l'on

rencontre un sculpteur avec des aides de ce genre. C'est l'usage moderne, et l'examen des pointes et ciseaux en bronze de nos musées m'a suggéré l'idée que je viens de vous rappeler et que j'ai exposé à M. Berthelot.

"2. Il n'y a rien ni sur les monuments ni dans les musées qui indique que les Egyptiens aient employé ou même connu l'acier trempé."

The following is a translation of Mr. Maspéro's letter:—

"I was unable to answer your letter until after my return to Cairo, which occurred only a few days ago. This is briefly what there is to be said on the subject.

"1. What I said to Mr. Berthelot was not quite accurately reported; I was speaking of experiences of mine about 1884-1885 at Luxor. In order to obtain an insight into the technique of the Egyptian sculptors, I ordered from a native copyist of great ability a granite statue in Egyptian style. Being present during the production of this statue, I observed that the workman used for cutting the stone points of soft iron with wooden handles. He had some fifty of these at his disposal, which he placed in the handle as he needed them. Each point became softened after three or four mallet strokes at the most. He then threw this away, took another, and an assistant put the softened points in the fire and then hammered them out to put a new head on them. The statue was made—or rather the bust, for it only represented a half figure—in about three weeks, all the work being done practically, as one might say, by wearing out the iron and then restoring its point by forging. By being hammered this point became very hard.

"In the monuments there are no representations where a sculptor is to be found with appliances of this kind. It is the modern usage—and by examining the bronze points and chisels in our museums, the idea was suggested to me which I have just called to your attention, and of which I spoke to Mr. Berthelot.

"2. There is nothing either on the monuments or in the museums to indicate that the Egyptians used or even knew of hardened steel."

As an observation on the above, the author would point out
1912.—i.

that the ancient Sinhalese specimens now described—at any rate as regards the chisel—show distinct signs of cementation, so that a pointed chisel, by being heated for some time in the smith's hearth, or in some other manner, might become carburised, and therefore much harder at the point even if it was not quenched. It would, therefore, seem from the antiquity of the specimens which were obtained by the author from the Colombo Museum, that at any rate at least 1400 years ago, chisels of iron, apparently with carburised or cemented edges, were known and in use. It is therefore very probable that the same knowledge existed in Egypt.

SECTION G.

HARDNESS RETENTIVITY OF ANCIENT SPECIMENS OF IRON AND STEEL.

The retention of the hardness of ancient specimens of iron and steel is dealt with by Dr. Cecil H. Desch in his recent interesting work on Metallography.

Dr. Desch speaks of the phases retained by quenching being commonly spoken of as metastable. He considered, however, that whilst experimental proof had not been produced, we were bound to assume that the metastable limit had been passed, and that the systems are correctly described as labile, not as metastable. Quenched specimens, therefore, tend spontaneously to assume an equilibrium condition by undergoing the transformation which was suppressed by quenching. It is uncertain how far the spontaneous change can proceed at ordinary temperatures. White tin, which is only stable above 18° , does not change into grey tin at 0° unless brought into contact with the new phase. Below 0° the change can occur spontaneously, although even at low temperatures it may fail to occur when the tin is kept for long periods. This would seem to indicate that the metastable limit for tin lies much below 0° .

Dr. Desch considers that hardened steel is undoubtedly labile at the ordinary temperature; and the presence of the

stable phase is not necessary to initiate change. But there is little evidence that softening of steel takes place spontaneously unless the temperature is raised. He also states that Japanese swords of the fifteenth century, when carefully preserved, are found to be as hard at the edge as if newly hardened; it would, therefore, seem that no appreciable return to the stable state takes place in the course of several centuries at atmospheric temperatures. On the other hand prolonged heating of hardened steel even at 100° produces an appreciable softening, and heating at 150° , in a few minutes. The whole question of labile and metastable conditions in undercooled solid alloys demands fuller investigation.

The above statement by Dr. Desch is particularly interesting in regard to the present paper, because it shows that material of ancient origin, although found in soft condition, may really have originally been quite hard. Thus, the edge of the ancient chisel, described in Experiment No. 2252, distinctly shows a defined structure in certain parts, differing from the other portion, apparently martensitic, as if it had once been in the hardened condition, but by the efflux of time had gradually assumed the condition in which it was now found—that is soft. On the other hand, this particular chisel may not have been hardened, although the microstructure, by the presence of troostite, seems to indicate that this may have once been the case.

SECTION H.

DESCRIPTION OF THE RESEARCH EXPERIMENTS.

Details of the various specimens and an account of the research conducted, with the results achieved, may now be given, these experiments being carried out by the author at the Hecla Works Laboratory and Research Department.

Experiment No. 2252.—This was carried out upon the ancient Sinhalese chisel, being specimen marked No. 1 by Dr. Willey, and shown in Fig. 1, Plate XV. This dates back to the fifth century. The specimen was very rough, but without scale, and had an undulating surface, possibly due to unequal corrosion, and it is possible that the material was forged with

rough implements of stone. The chisel was about 10 inches in length, and at the upper portion away from the edge about $1\frac{3}{16}$ inch square, $\frac{1}{16}$ inch by $\frac{9}{16}$ inch in the centre, tapering to a point as with modern tools.

TABLE I.—*Composition.*

	Per Cent.
Carbon	traces
Silicon	0.12
Sulphur	0.003
Phosphorus	0.28
Manganese	nil
Iron	99.3

The difference represents slag and oxide.

Specific gravity, 7.69.

Tensile Strength.—The Fremont shear test showed 16 tons per square inch elastic limit, 26 tons per square inch breaking load.

Shock Test.—The shock test, on un-nicked specimen, showed 17 kilogrammes, with 85° bend before breaking.

Hardness.—The Brinell ball test showed hardness numbers of 144 and 144 on the opposite side of the chisel.

The scleroscopic hardness number was 35.

The fracture was unsound, apparently owing to the existence of unsoundness or blowholes. The crystalline structure showed large sparkling crystals. The microstructure of the specimens shown on Plates XVIII., XIX., and XX. brings out several points of interest. The transverse section shows that this chisel has been carburised, the section showing the carburised areas to be on two sides. The carburisation varies on the two faces from saturation point (0.9 per cent.) to about 0.2 per cent. carbon on the outside edge, and the depth of the carburisation from the edge inwards is also shown to be variable. The presence of martensite and hardenite (Figs. 1 and 2, Plate XVIII., and Fig. 2, Plate XX.) suggests the important information that the chisel has been quenched. Some of the crystals give evidence of a structure probably due to impurities of phosphorus and sulphur.

The longitudinal photographs of both the chisel and the nail show this structure. Fig. 2, Plate XIX. represents the transverse section, and Fig. 2, Plate XX., the longitudinal.

Further micro-sections were prepared from the specimen cut from the nose of the ancient chisel. These are shown by Figs. 1 and 2, Plate XVIII. Fig. 1 represents a longitudinal section from the chisel point where worn down; and Fig. 2 in the main approximately shows the outside edges of the chisel, as indicated by the black lines. These outside edges are naturally somewhat out of focus. These photomicrographs appear, in the author's view to carry evidence that the chisel has been quenched, for the structure is in parts martensitic. Troostite is certainly also present, which is probably the result of tempering by the long lapse of time.

The author believes this to be the first time there has been put on record evidence of the art of cementation having been known 1500 to 2000 years ago, as shown by these specimens; probably, therefore, such knowledge could be traced back still further.

Experiment No. 2253.—This was carried out upon the ancient Sinhalese nail, specimen marked No. 2 by Dr. Willey, and is shown in specimen Fig. 2, Plate XV. This is probably of the same origin and age as the chisel just described. This nail is about $13\frac{1}{2}$ inches in length, and $\frac{5}{8}$ inch \times $\frac{9}{16}$ inch at the point; the extreme point is missing.

TABLE II.—*Composition.*

	Per Cent.
Carbon	traces
Silicon	0.11
Sulphur	nil
Phosphorus	0.32
Manganese	nil

Specific gravity, 7.69.

Tensile Strength.—The Fremont shear test showed 11 tons per square inch elastic limit 21 tons per square inch breaking load.

Shock Test.—The shock test on un-nicked specimen was 0.5 kilogramme \times 1 degree—that is, it was very brittle.

Hardness.—The Brinell ball test showed hardness numbers of 117 and 209 on opposite side of the nail.

The scleroscope hardness number was 44.

The fracture revealed a fine bright crystalline structure.

The microstructure. Fig. 1, Plate XVII., and Fig. 1, Plate XIX., indicate a remarkable conglomeration.

Fig. 1, Plate XVII., shows a weld running diagonally across the section, and along the edges of the weld there are carburised areas. Another notable point is that on one side of the weld the slag shows the effect of the forging, whereas on the other side there is no such sign. The specimen is covered with slip bands, and has evidently undergone severe hammering, probably in its use as a nail. The carbon in the carburised areas exists as granular pearlite. Fig. 1, Plate XIX., is a transverse section, and Fig. 1, Plate XVII., a longitudinal section.

The longitudinal photographs of both the chisel and the nail (Fig. 2, Plate XX., and Fig. 1, Plate XVII.) show evidence of a structure.

The fragment from the nail was heated and forged well up to about 1150°C . As forged the Brinell ball hardness number was 120. The same material heated to 1050°C . and quenched in water showed 130 Brinell ball hardness number, showing that it was not hardened by quenching.

Experiment No. 2254.—This was carried out upon the ancient Sinhalese billhook, specimen marked No. 3 by Dr. Willey, and is shown in Plate XVI. The specimen was very corroded, being covered with a thick brown rust.

The billhook is about $12\frac{1}{2}$ inches in length, $3\frac{1}{8}$ inches in width at the blade, the handle being $4\frac{1}{2}$ inches in length.

TABLE III.—*Composition.*

	Per Cent.
Carbon	traces
Silicon	0.26
Sulphur	0.022
Phosphorus	0.34
Manganese	traces

Specific gravity, 7.50.

Tensile Strength.—The Fremont shear test showed 16 tons per square inch elastic limit, with 29 tons per square inch breaking load.

Shock Test.—The shock test on un-nicked specimen gave 7.1 kilogrammes by 35° bend only.

Hardness.—The Brinell ball test showed hardness numbers of 153 and 166 on opposite side of the billhook.

The scleroscope hardness gave number 23.

The fracture showed bright crystalline structure, laminated appearance.

The report on the microstructure of the specimen, as shown by photomicrographs Fig. 2, Plate XVII., and Fig. 1, Plate XX., shows that it contains a large amount of slag, and appears to represent what would be now termed a somewhat low quality of wrought iron. There seems to be practically no carbon present, and therefore no evidence of treatment other than forging can be obtained. Fig. 2, Plate XVII. is the longitudinal section, and Fig. 1, Plate XX., the transverse section.

Special interest attaches to the analyses given, as they probably represent the only modern complete and accurate determination of the composition of known and authentic specimens of ancient iron.

The phosphorus is, it will be noted, high, from 0.28 up to 0.34 per cent., which, however, does not greatly differ from modern bar iron. The sulphur percentage is extremely low, showing that a very pure fuel—no doubt charcoal—was employed in the production of the material. There is very little silicon present, and manganese is entirely absent, which is somewhat remarkable, as nearly all iron contains some manganese. As the specimens from which to produce tensile bars were too small, these were obtained by means of the ingenious Fremont shear-test method. The tensile quality of the material averages about 26 tons per square inch, or a little higher than wrought iron. This no doubt is owing to the considerable percentage of phosphorus present, which stiffens or hardens iron. The Fremont shock tests show fair results on the specimen taken from the chisel, namely 17 kilogrammes, with 85° bend. The other specimens, however, show much lower figures, namely the nail (1 kilogramme by only 1° bend), and the billhook (7 kilogrammes by 35° bend). The hardness by the Brinell method varied from 117 to 166, one result from the nail showing 209; but this is abnormal, and cannot be accepted as representative. The scleroscope tests varied from 25 to 44, and as a comparison it may be mentioned that water-quenched carbon steel by this latter method shows 100, and ordinary wrought iron about 20.

From the microscopical examination and from the other tests carried out, the specimens represent a material of the type known as wrought iron, and not steel. The specimens somewhat resemble the material known as puddled iron, and appear to have been made from somewhat impure ore. The material is very low in its percentage of carbon, and, excepting phosphorus, also other impurities. There is present, in a lumpy, irregular form, quite a large amount of slag, indicating that the material has not been submitted to anything like the amount of squeezing and forging that modern wrought iron undergoes.

On etching the longitudinal micro-sections for tests for phosphides, the nail showed a clean weld of pure iron on the one side and impure wrought iron on the other. Whereas the former is free from phosphides, the latter etches quite black, with 10 per cent. CuCl_2 , showing presence of a large amount of phosphide of iron. The specimens from the chisel and billhook were also etched as macro tests. These are shown in Plate XXI.

SECTION I.

CONCLUSION.

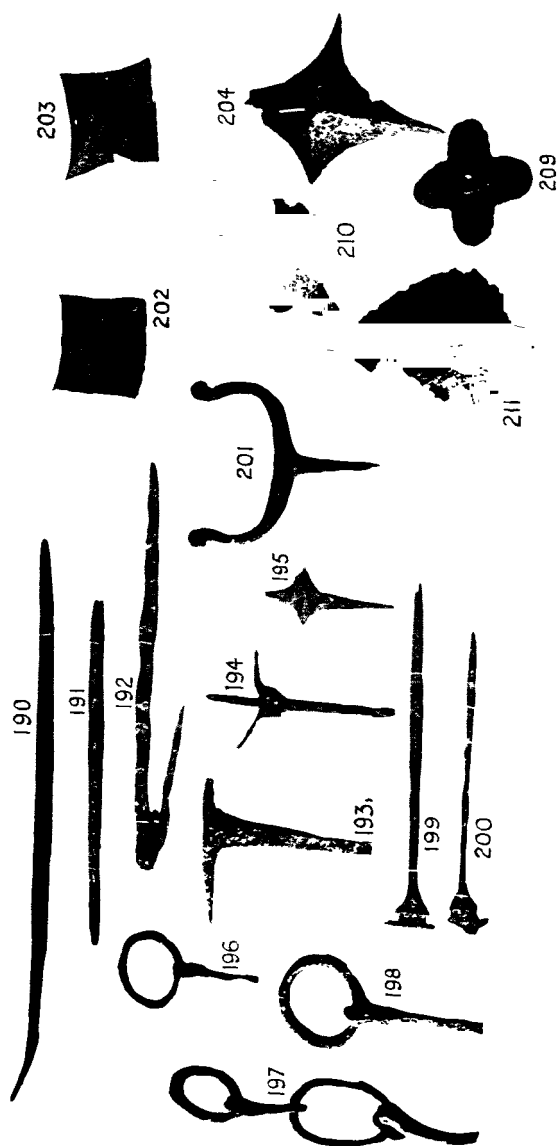
In concluding this paper, the author trusts that the facts set forth in this research add definite knowledge regarding ancient iron and steel. The production of such iron of satisfactory quality appears to have taken place on a large scale. The results set forth in this paper, and the various facts referred to regarding the production and use of iron in India, show that in ancient times metallurgical knowledge existed to quite a considerable degree.

This is not unnatural, seeing that Dr. V. Ball M.A., F.G.S., in his admirable and exhaustive work on the "Geology of India," shows that the deposits of iron ore are very numerous in our Indian Empire. He adds his belief that "there are distinct evidences that Wootz was exported to the West in very early times, possibly 2000 years ago." Without doubt, therefore, as the natives of India had in bygone ages ample

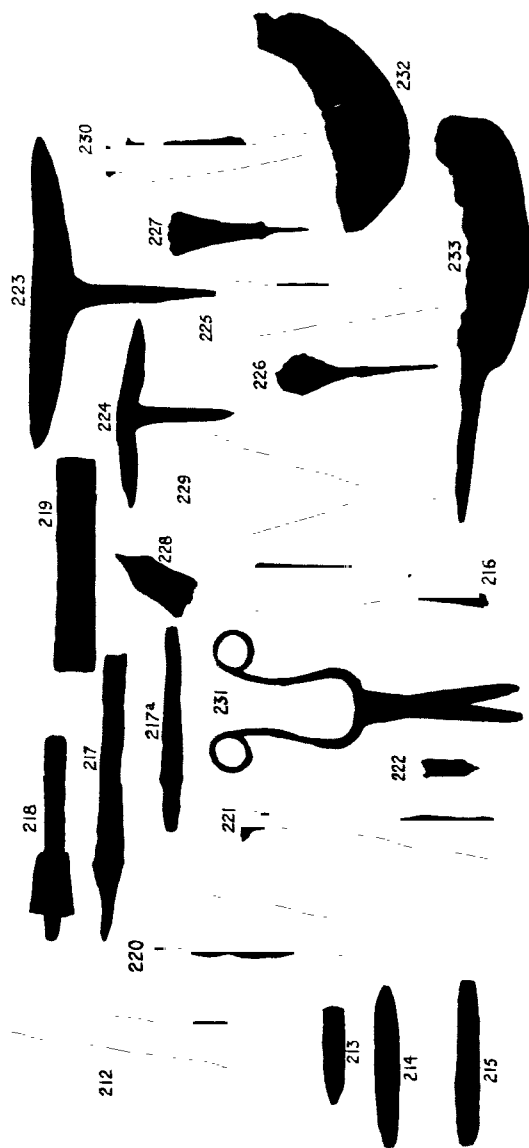


*180.	Arrow head	.	.	Signiya.
181.	" "	.	.	Pankhiya, Annadhapura.
182.	" "	.	.	Signiya.
183.	" "	.	.	North of Hospital Premises, Annadhapura.
184.	" "	.	.	" "
185.	" "	.	.	Kali Devale, Polonnaruwa.
186.	Spear head.	.	.	Polonnaruwa.
187.	Sword blade	.	.	" "
188.	Guard of a sword	.	.	Kali Devale, Polonnaruwa.
189.	" "	.	.	" "

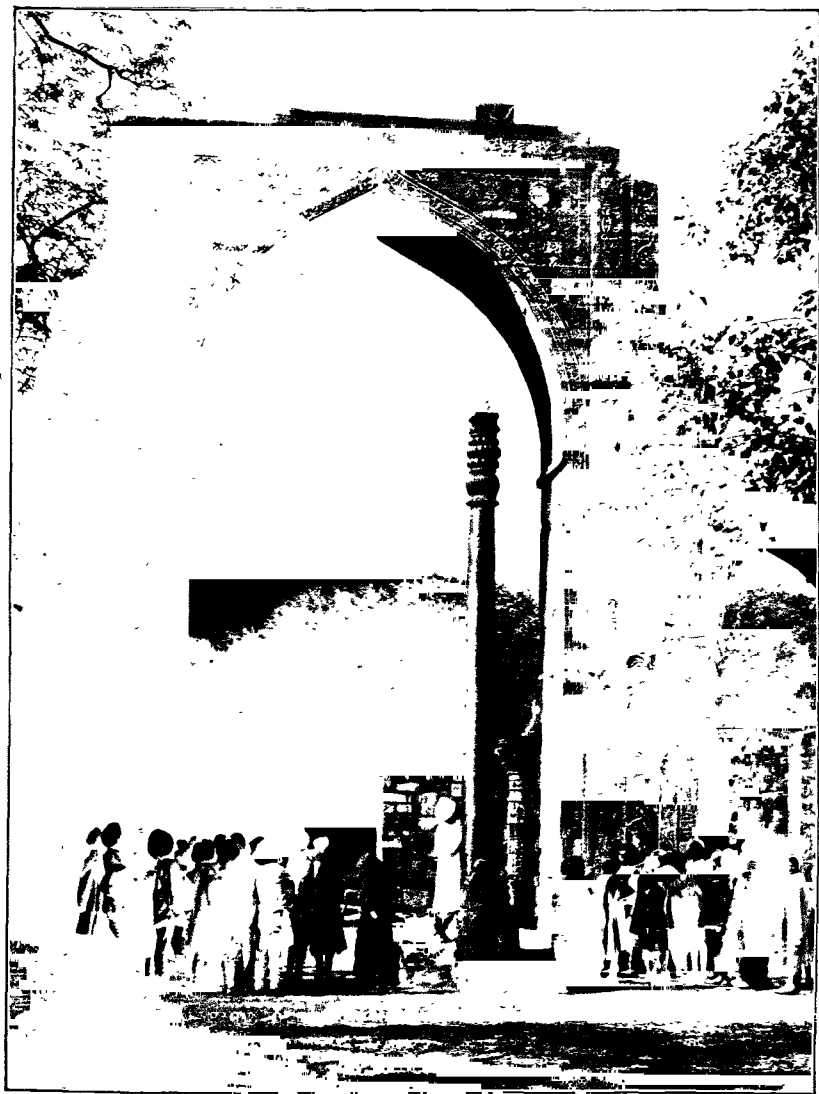
* These figures represent the numbers of the specimens as arranged in the Colombo Museum.



190.	Iron rod	Siva Devale, Polonnaruwa.
191.	" "	Signiya.
192.	Pointed object	" "
193.	" "	North Central Province.
194.	" "	" "
195.	" "	" "
196.	Ring and Eyespake	" "
197.	" "	" "
198.	" "	" "
199.	Old pen (stylus)	Signiya.
200.	" "	" "
201.	Cutch for receiving the carrying pole of an image	North Central Province.
202.	Door boss	" "
203.	" "	Near Arayagiri, Anuradhapura.
204.	" "	" "
205.	" "	Signiya.
206.	" "	Siva Devale, Polonnaruwa.
207.	" "	Pinkulhiya, Anuradhapura.
208.	" "	" "
209.	" "	" "
210.	" "	" "
211.	" "	" "



212. Chisel	Sigiriya.	223. Cutting tool	Siva Devale, Polonnaruwa.
213. Stone-cutting chisel	North end of Vessagiri, Anuradhapura.	224. " "	" "
214. " "	Site of Buddhist Reliquary, Anuradhapura.	225. " "	Sigiriya.
215. (Not stated)	" "	226. " "	North Central Province.
216. Chisel	North Central Province.	227. " "	" "
217. " "	Sigiriya.	228. Plane blade (?)	" "
217a. " "	Vijayarajana, Anuradhapura.	229. " "	" "
218. Chisel (with collar)	" "	230. Knife	Paliyankulam Monastery, Anuradhapura.
219. Double-edged tool	North Central Province.	231. Pair of scissors	Hospital premises, Anura- dhapura.
220. " "	Alhayanigiri, Anuradhapura.	232. Kathe	Near Aytton Road, Anura- dhapura.
221. Edged tool	Sigiriya.	233. " "	Sigiriya.
222. " "	North Central Province.		



The Iron Pillar at Delhi

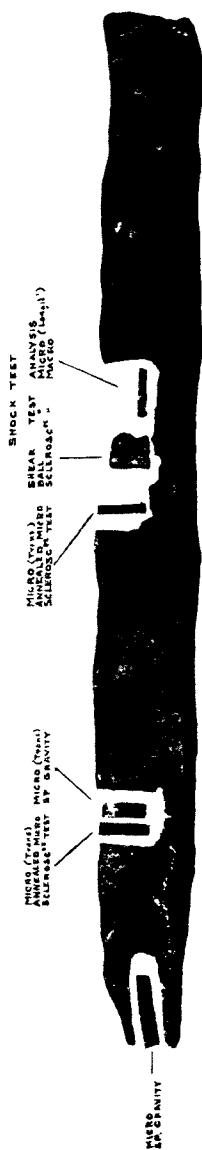


FIG. 1.—Ancient Chisel from Signiya (5th century A.D.).



FIG. 2. Ancient Nail, 13½ inches in length, from Signiya (5th century A.D.).

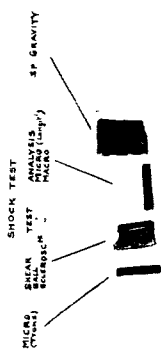


FIG. 1.—Ancient Kelta or Billhook.

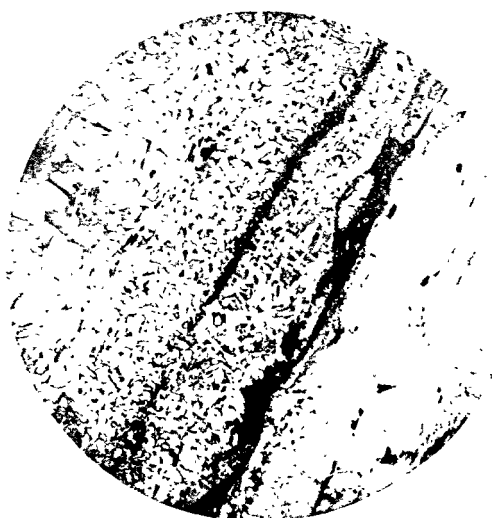


FIG. 1.—No. 317B. Nail. Longitudinal, showing weld.
Magnified 80 diameters.



FIG. 2.—No. 319A. Billhook. Longitudinal
Magnified 80 diameters.

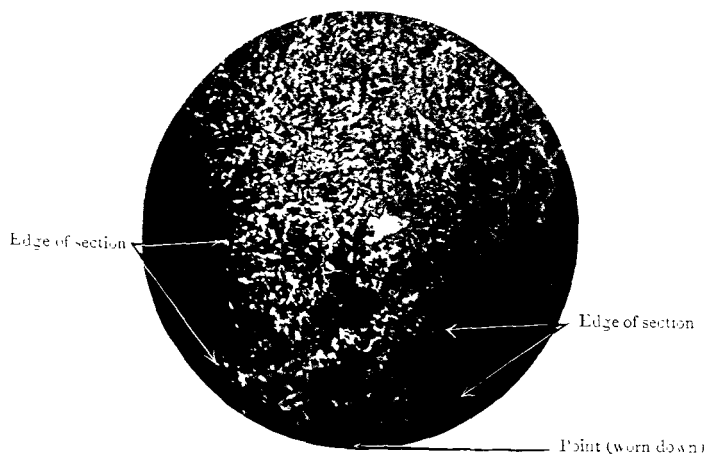


FIG. 1.—No. 389A. Chisel, from point. Longitudinal section.
Magnified 80 diameters.



FIG. 2.—No. 389C. Chisel, from point. Longitudinal section.
Magnified 80 diameters.



FIG. 1.—No. 317. Nail. Transverse
Magnified 80 diameters

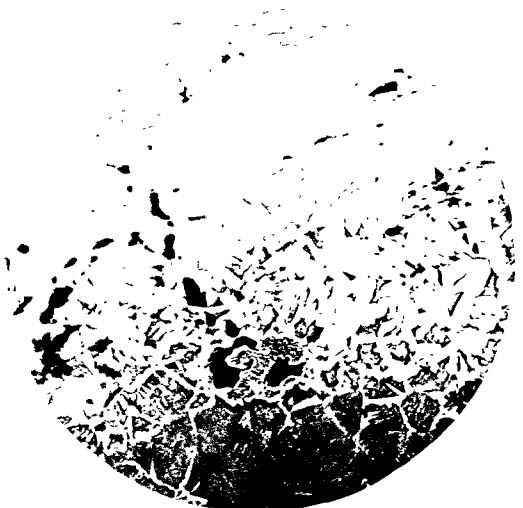


FIG. 2 —No. 318. Chisel. Transverse
Magnified 80 diameters

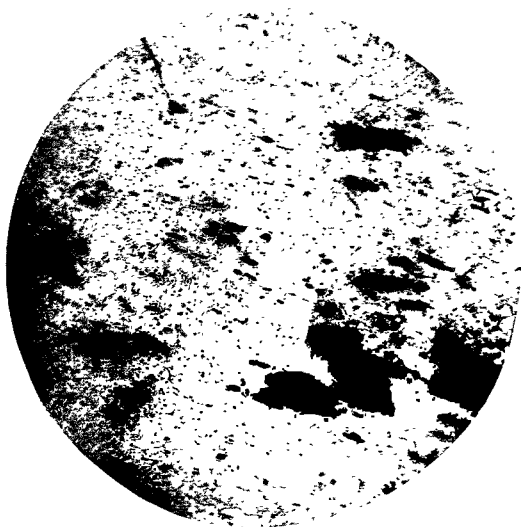
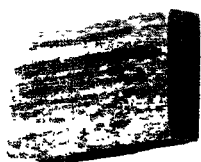


FIG. 1.—No. 319. Billhook. Transverse.
Magnified 80 diameters.



FIG. 2.—No. 318a. Chisel. Longitudinal.
Magnified 80 diameters.



BILLHOOK



NAIL



CHISEL

Macro-Tests, Longitudinal Sections from Ancient Tools.

sources of iron ore at their disposal, they knew how to produce iron and steel. It seems highly probable, therefore, that they did actually export their products to Egypt.

If, too, the photomicrographs of the ancient Sinhalese chisel represent the current practice of that time, as probably was the case, the fact that the art of case-hardening or cementing and carburising wrought iron—afterwards quenched in order to produce articles with hardened cutting edges—was known, is an important piece of evidence, and proves that the art of iron and steel manufacture must at that time have been of quite a high order. In fact, combined with the information submitted regarding the remarkable wrought iron pillars at Delhi and Dhār, the pillar at the latter place being at least 44 feet in length, and of considerable diameter, it would appear that even the production of masses which were not possible in Europe until quite recent times, were then undertaken. Beyond Nature's own productions of large meteoric masses, the author believes he is correct in stating that no such large masses were ever known to have been produced in the Western portion of our globe at this period. Eastern knowledge was, therefore, much superior to that of Europe.

It is important to know whether the facts stated in this paper warrant the conclusion, as they appear to do, that knowledge existed in ancient times with regard to hardening carburised iron. If they do, we should then have a satisfactory explanation of how the great works of stone, such as those seen in Egypt, were carried out in past ages—that is, probably by means of iron or steel tools, hardened and tempered to carry a cutting edge.

The author will be more than repaid for any trouble he has taken if this paper throws light upon points which have been before obscure, or if it adds but a small chapter to the knowledge and history of the fascinating metal iron—the metal by the aid of which so much has been done to modify and revolutionise the world, specially in its more recent and modern history.

As regards this revolution, one simple illustration will suffice. In the paper to the Royal Society by Faraday and Stodart on "The Alloys of Steel," in 1822—not very long ago—it is

described how the various specimens were carefully prepared in London and sent to Sheffield to be melted and cast under the supervision of an "intelligent and confidential agent." Although this was only eighty-nine years ago there was then no other way of forwarding such specimens except by road—no "iron" road existed!

It is hoped, therefore, that the research may be a suitable addition to the interesting one regarding Indian steel already set before the Royal Society by one of its Fellows, Dr. Pearson, now more than a hundred years ago.

The author takes this opportunity of thanking His Excellency the Governor-General of Ceylon, Sir Henry McCallum for his kindness in permitting these valuable specimens to be made available from the Colombo Museum; Dr. Willey, F.R.S., the then Director of the Museum, for the trouble he also took in the matter; and Mr. G. A. Joseph, the acting Director of the Colombo Museum. To Mr. G. C. Lloyd, the Secretary of the Iron and Steel Institute, and his assistant, Mr. L. P. Sidney, for information furnished: Dr. A. K. Coomaraswamy, for his permission to make use of photograph No. 10, taken from his book on "Mediæval Sinhalese Art"; Miss Hughes, the Secretary, and her assistant, of the Royal Asiatic Society, for affording help with reference to the inspection of that Society's proceedings: and to the members of his own Research staff, Messrs. I. B. Milne, T. G. Elliot, and others, for the assistance they have given in carrying out this research, his thanks are likewise due.

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The author has since been able to obtain specimens from the actual Delhi Pillar. On analysis the following results were obtained:—

Carbon	0.080 per cent.
Silicon	0.046 "
Sulphur	0.006 "
Phosphorus	0.114 "
Manganese	nil
Total of elements other than iron	0.246 "
Iron	99.720 "
Total	99.966 "

Specific gravity, 7.81 per cent.

Ball hardness No. 185

It will be noticed that the material is an excellent type of wrought iron, the sulphur being particularly low (0.006 per cent.), indicating that the fuel used in its manufacture and treatment must have been very pure (probably charcoal). The phosphorus is 0.114 per cent. There is no manganese present; a somewhat special point, as wrought iron usually contains manganese. The iron was ascertained by actual analysis, and not "by difference." This is probably the first time that a complete analysis has been given of the material of which this Pillar is composed. The similarity of the composition both of the Pillar and of the Sinhalese specimens suggests that the processes of manufacture likewise resembled each other.

313.

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1912. H. G. Graves, "Further Notes on the Early Use of Iron in India," *Journal of the Iron and Steel Institute*, 1912, No. I. p. 187.

DISCUSSION.

Sir ROBERT HADFIELD, F.R.S., Past-President, in introducing his paper, said that with reference to some of Professor Louis' remarks upon the previous paper, he (Sir Robert) had, upon the table, a photomicrograph from the chisel referred to. On analysing that specimen it was found that the carbon percentage was quite considerable. On one of the sides of the chisel no less than 0·90 per cent. of carbon was found to be present, which might have been, as Professor Louis suggested, the result of the particular kind of method of manufacturing the material in its first stage, and if that was so the carbon might not be due to cementation. At any rate, a high percentage of carbon was really present, varying from 0·2 to 0·9 per cent. The depth of the carburised layer seemed to be variable. The chisel seemed to show evidence that it had been quenched, although some authorities thought a similar structure could be produced by hammer hardening; in any case it was evident that many thousands of years ago the manufacture of iron and steel was well known. Since the paper was written, one of the members of the Institute, Sir Joseph Jonas, had sent the author a photograph of one of the Pompeian frescoes showing two cherubs forging a metallic product upon an anvil. Whether the products being worked were iron it was difficult to say, but the tools employed must surely have been of iron. Sir Joseph had also sent him the analyses of some specimens of old steel which his son obtained in India—in one case the carbon was as high as 1·84 per cent.

Owing to the great difficulty of obtaining ancient specimens, those now exhibited and the bloom shown by Sir Hugh Bell represented particularly valuable evidence of the use of iron and steel in early ages. In Ceylon, where the author's own specimens came from, the air was particularly dry, which probably partly explains why the specimens in the Colombo Museum collection had been so well preserved from rust.

Sir HUGH BELL, Bart., Past-President, said that the paper by Sir Robert Hadfield dealt with a remarkable series of early iron specimens, and he believed they went to confirm the opinion entertained that in early days iron was unquestionably made direct from the ore. It was probable that occasionally in accidental circumstances something which distinctly resembled cast iron was made, and the makers were probably very much perplexed at it, as they wanted to obtain iron that was easy to manipulate. In dealing with that subject he was aware, however, that he was treading on somewhat dangerous ground, because there were those who believed that certain Roman implements found in Great Britain were made of cast iron, and his friend Dr. Greenwell of Durham was one of them.

CORRESPONDENCE.

Professor J. O. ARNOLD, F.R.S., Bessemer Medallist, wrote that he had read Sir Robert Hadfield's paper with extreme interest, and thought it was well that such papers should, from time to time, be presented to the Institute to remind the members of the small beginnings of that huge industry to which they were devoted, and which now practically dominated the civilised world.

The paper was extremely interesting as giving concrete data proving the existence of iron and steely iron weapons of peace and war of a date shortly after the beginning of the Christian era. It was extremely difficult to attempt to differentiate between the Stone, the Bronze, and the Iron Ages, as they obviously overlapped in different districts of the world over long periods of time; but apart from concrete data, such as that presented by Sir Robert Hadfield in his admirable paper, there was a question of collateral evidence, and perhaps it might be permitted to develop that evidence, which threw a different aspect over the whole question. In his (Professor Arnold's) opinion, iron, and even steel, existed even back to the border-land where pre-historic time passed into historical time. Homer, whose writings were generally assumed to be the first authenticated literature subsequent to the time of Moses, wrote in the *Odyssey*, Book IX. (according to Pope's translation), the following lines:—

“ And, as when armourers tempered in the ford,
The keen-edged pole-axe or the shining sword,
The red-hot metal hisses in the lake;
Thus in his eyeballs hissed the plunging stake.”

Those lines were quoted by Roscoe and Schorlemmer in their classical Chemistry, and they very truly remarked, “ This description could have reference only to steel ”; and probably referred, in Professor Arnold's opinion, to the puddled steel of the period. Turning to Great Britain, there was historic evidence that Boadicea, the British “ Warrior Queen,” smarting under her wrongs and oppressions, in A.D. 50 gathered together an army, and fiercely attacked the Roman conquerors in a great battle before Colchester; she and her Britons totally annihilated the Ninth Roman Legion. She attacked a second Roman army at St. Albans, totally defeating it, and the same fate overtook the Romans near London. Tacitus, the Roman historian, estimated that in those three battles the loss of the Roman legions and their auxiliaries reached the huge total of 70,000 men. It followed, therefore, that shortly after the beginning of the Christian era, Boadicea must have had under her command something like 100,000 troops, who would be armed with swords and spears of iron or steely iron, in addition to the great scythes on the axles of the war chariots of the ancient Britons. It therefore seemed certain that long before that there must have been in ancient Britain huge armouries for the manu-

facture of weapons, and that the discovery of the reduction of iron must have preceded by many years its manufacture on so very large a scale.

Professor CARL BENEDICKS (Stockholm University) wrote that every one interested in metallography would understand the value of Sir Robert Hadfield's researches. The interest attaching to such ancient specimens of iron might even be greater than that claimed by the author. Sir Robert held the view, which might be said to be widely adopted, and had been advocated by the late Secretary of the Institute, Mr. Bennett H. Brough, that the use of iron had existed from the very earliest periods in the history of mankind, and that the non-existence of remains of those early periods should be ascribed to oxidation. Professor Benedicks had had the opportunity of discussing the matter with an eminent representative of another view of the subject, the well-known Swedish archaeologist, Professor O. Montelius, who had consecrated a considerable part of his life to the study of the early history of iron. As expounded by Professor Montelius, at the Ghent Congress in 1907, the assumption as to the very ancient origin of the use of iron was based mainly on the three following considerations:—

(1) The erection of the pyramids. The inscriptions made by the Egyptians in hard stone were difficult to explain without admitting the use of iron, as pointed out by Mr. Maspéro. The chemical and metallurgical knowledge at that period was so considerable that it was unreasonable to imagine that the early Egyptians were unaware of how to prepare iron. However interesting such considerations, they afforded no proof of the early use of iron, and the question involved only the existence of specimens which, although scarce, was incontestable.

(2) Hieroglyphics which had been identified with the word "Iron" occurred in the very earliest ages. Professor Montelius, however, pointed out that they could just as well bear the signification of "metal" used for weapons or tools: first copper and bronze and later iron. That that was the case was known by reference to other races. Thus, the Sanskrit word "Ayas" signified in the first instance copper or bronze and later came to mean iron.

(3) The specimen of iron taken from the Great Pyramid, and some other finds which had been referred to. They had not been so carefully described, nor their exact manner of occurrence explained sufficiently, to prove that they might not have been of later origin. A very interesting discovery made some years ago by Professor Flinders Petrie¹ of a shapeless iron mass surrounded by some bronze tools dating from the Sixth Dynasty (about 2600 B.C.) could not be taken as a proof that iron instruments were manufactured at that time. On the contrary, it was rather a proof that at a period when bronze was still being used for the manufacture of tools, the produc-

¹ "Man," a *Monthly Record of Anthropological Science*, vol. iii. p. 147, 1903.

tion of iron had been discovered, but the methods of working it were not known.

The chief arguments against the very early use of iron were the following:—

(1) Mural pictures from the "Old Empire" (prior to about 2000 B.C.) frequently showed weapons of copper or bronze, coloured red or yellow, but never of iron (coloured blue) as in paintings of the "New Empire" (after 1580 B.C.). Lepsius, who believed in the very early use of iron, was much struck by that fact, which he was unable to explain.

(2) As lately shown by Mr. Hall¹ in the long tribute lists of the Eighteenth Dynasty (about 1580 B.C.), iron was never mentioned; but during the Nineteenth Dynasty it occurred in a sacred inscription at Abu Simbel, in which the god Ptah was made to say that he had formed the limbs of King Rameses II. of electrum, his bones of bronze, and his arms of iron. That was the earliest literary mention of iron, with regard to which no doubt had been entertained. From that time onwards, pictures showed weapons of iron, according to Lepsius, and actual specimens had been preserved. Thus Hall pointed out that Professor Petrie² recorded the existence of an iron halberd-blade of Rameses III.'s time as one of the earliest known specimens of an Egyptian iron weapon; its date was about 1200 B.C.

(3) In all tombs and dwellings from the time of the Nineteenth Dynasty, explored by Professor Flinders Petrie, in the cities of Kahun and Gouroh, where immense quantities of flint, copper, bronze tools, wooden objects, and papyrus were dug out, no trace either of iron and iron rust could be observed.

There was thus, in Dr. Benedicks' opinion, good modern evidence of the truth of the statement made by Professor Montelius twenty-five years ago that the use of iron in Egypt was not earlier than 1500 B.C., and that it was not until about 1200 B.C. that that metal assumed importance in the Nile valley. Evidences gathered from other races agreed with that conclusion. The interesting correspondence of Mr. Maspéro quoted by Sir Robert also supported Professor Montelius' contentions. The buried Sinhalese cities were now stated to date back to about 500 B.C., and even if the specimens described by Sir Robert Hadfield did not extend as far back, it seemed highly probable that they were more nearly contemporary with the earliest use of iron than has been assumed.

Dr. A. K. COOMARASWAMY (London) wrote that Sir Robert Hadfield's paper was not only of general interest as an important contribution to culture-history, but of special interest to students of the history of civilisation in India. He hoped sincerely that Sir Robert might be able to complete the work from that point of view, by publishing the results of an examination of the iron and steel of

¹ "Man," a Monthly Record of Anthropological Science, vol. iii. p. 147, 1903.

² "Abydos," vol. ii. p. 33, plate II. Fig. 10.

modern manufacture in India and Ceylon, as there was no doubt that the ancient methods had been continuously handed down. He might mention that those interested would find specimens of Sinhalese steel and crucibles, made for him a few years ago, in the Museum of Practical Geology at Jermyn Street. One other matter might be referred to in connection with the general subject of Indian metallurgy: that there remained an important field for study in the Indian bronzes and other alloys. It was to be hoped that some competent metallurgist might take up that research. It had quite a practical bearing for artists and manufactures: for, on the one hand, the colours of the various alloys were of much interest, and on the other, it might be noted that some Indian brasses tarnished rapidly, while others, mostly the whiter kinds, resisted the London fogs much longer.

Dr. ALLERTON S. CUSHMAN (Washington, U.S.A.) wrote that he had great pleasure in contributing to the discussion of such an interesting and scholarly presentation of an important subject as was given in the paper by Sir Robert Hadfield. The history of the past frequently pointed the way to progress for the future, and that was likely to be quite as true in the metallurgical arts as in social or political development. He (Dr. Cushman) was particularly interested in the extraordinary resistance to corrosion that was evidenced by those ancient irons. It should not be forgotten that the Sinhalese specimens described by Sir Robert Hadfield must have been stowing the surface of the earth, or have been more or less deeply buried, for many centuries, and that they unquestionably represented the "survival of the fittest" among the products of ancient metallurgy. Chemical and physical examinations of such ancient specimens might point the way to practical improvement in our own age, for one criticism that was often passed on modern steels was that their tendency to corrode and disintegrate stood in direct ratio to the rapidity with which they were manufactured. In that connection, he (Dr. Cushman) thought that a quotation from a paper on the conservation of iron, which he had printed in the *Journal of the Franklin Institute* for April 1911, might be appropriate:—

"We live in a practical age, and it is essential that we should consider our great industrial problems from a practical view-point. No sensible persons would venture to propose a return to the old hand-worked methods of manufacture, for modern conditions could not support such an industry. In the old Wootz and Catalan processes very pure magnetite and hematite ores, first pulverised and thoroughly lixiviated and washed, were used. They were then little by little puddled out by burning with charcoal in a pit or oven, and subsequently beaten and forged by patient industry to the desired form. It seems to be a law of Nature that her materials should respond to the manipulations of the hands of man, and acquire properties that machinery cannot give. As an example of this, we have only to remember the everlasting qualities of the hand-worked lacquers and enamels of the Orient, and compare them with the

machine and brush laid coatings of our own industrial processes. The poet Virgil, who lived before Christ, has drawn a picture which brings vividly to mind the intense manual labour involved in early metallurgical operations:—

'As when the Cyclops, at th' almighty nod,
New thunder hasten for their angry god,
Subdued in fire the stubborn metal lies:
One brawny smith the puffing bellows plies,
And draws and blows reciprocating air:
Others to quench the hissing mass prepare:
With lifted arms they order every blow,
And chime their sounding hammers in a row.
With laboured anvils Etna groans below.
Strongly they strike; huge flakes of flames expire:
With tongs they turn the steel and vex it in the fire.'¹

"The nineteenth century ushered in the age of steam, and from this point the history of iron exerts an even more potent influence than before over the development of the human race. The names of Watt, Stephenson, Bessemer, and Siemens will never require bronze monuments to perpetuate them, for as long as iron is made or moves they will be remembered."

The above quotation presented an interesting picture of the art of ancient metallurgy as Virgil was familiar with it.

As far as the chemical constitution might be taken as having a bearing on resistance, the specimens described by Sir Robert Hadfield were suggestive and interesting. It was to be noted that all the specimens were free from manganese and sulphur, but high in phosphorus. The writer had in his possession some wrought nails which were known to have been used in the construction of the Richmond (Virginia) Masonic Hall in 1807. For a hundred years those nails were in service, and as the old weather boarding rotted away they stood half-driven into the old oak studdings, partially exposed to the weather. It was most remarkable that even the sharp edges of the hand-forged nail heads had not suffered in the least, and were as sharp to-day as when turned out from the ancient smithy. That was clearly shown in the accompanying illustration (Fig. 1). The chemical analysis of that old nail was curiously similar to that of Sir Robert Hadfield's Sinhalese specimens, being low in manganese and sulphur and high in phosphorus. The analysis was as follows:—

	Per Cent.
Sulphur	0·013
Manganese	0·06
Carbon	0·03
Phosphorus	0·205
Silicon	0·121
Copper	0·027
Oxygen	0·150

It would be interesting in the face of that coincidence to see whether low manganese with low sulphur and high phosphorus would lead to high corrosion resistance in modern material. Fortunately the pro-

¹ Dryden's *Æneid*.

duction of commercially pure iron in open-hearth furnaces in America made possible the rephosphorising of pure iron, and he (Dr. Cushman) hoped to conduct experiments along that line.

It had recently been claimed that the addition of copper to steel increased the resistance to corrosion. An addition of 0.25 per cent. of copper to ordinary steel certainly reduced the solubility in dilute mineral acids, but there was no evidence that it led to longer life in service. When the old chain bridge at Newburyport, Massachusetts,¹ which was built in 1810, was recently taken down, the links were found to be remarkably free from corrosion. The first link analysed



FIG. 1.—Showing the relative corrosion of a modern steel nail and an old forged nail in service for 100 years.

was remarkably high in copper (0.35 per cent.). That appeared to substantiate the copper theory, but subsequent analyses of other links showed no copper present, so that again an illustration was afforded of the danger of basing conclusions on insufficient evidence. At his (Dr. Cushman's) suggestion, Sir Robert Hadfield had analyses for copper content made on the ancient Sinhalese specimens, and in a recent letter he made the following comments: "I have now made tests on the specimens in question with regard to copper with the following results:—

	Per Cent.
Billhook	0.012
Chisel	0.090
Nail	0.119

¹ A. P. Mills, *Transactions of the Association of Civil Engineers*, Cornell University, vol. xix. No. 7, April 1911.

I think in a general way those percentages might be termed coincidences; certainly they are not intentional additions of copper."

"As regards the effect of copper in adding resistance, all the specimens are more or less alike, whereas if this element has any influence the nail ought to have shown less corrosion than the others. I think, therefore, you are right in not accepting the theory that the addition of copper will enable iron and steel to resist corrosion."

In conclusion, Dr. Cushman took occasion to say that he would be glad to receive specimens, or information in regard to specimens, of irons of undoubted ancient origin which had proved to be highly resistant to corrosion.

Professor HENRI LE' CHATELIER, Bessemer Medallist, wrote that he had read with the greatest interest Sir Robert Hadfield's paper on prehistoric iron and steel. Apart from the archaeological importance of the question raised, it seemed to him that some of the observed facts possessed even greater practical interest. To begin with, the preservation for centuries, without alteration, of columns exposed to extremes of atmospheric conditions appeared to confirm the old-established opinion that iron manufactured by ancient processes offered greater resistance to oxidising action than modern steels. On referring to the analyses of those columns given by the author, one was struck by the almost complete absence, both of manganese and of carbon, which always occurred in noteworthy proportions in steels made by melting processes and also by the relatively high percentage of phosphorus. It was perhaps to the concurrence of those three factors that the exceptional durability of those ancient Hindoo irons was to be attributed.

The presence of troostite in certain portions of the iron which had been case-hardened and quenched was pointed out by Sir Robert Hadfield. It was legitimate to inquire whether the martensite could not have been transformed, in time, into troostite by spontaneous annealing carried out at the ordinary temperature. The law as to the variation of the rate of reaction in proportion to the temperature would foreshadow that transformation and the partial demagnetisation of magnets containing carbon seemed experimentally to confirm that presumption. It would be interesting to submit the problem to even more careful experimental checking. Would it not be possible to deposit at the International Bureau of Weights and Measures in France and at the National Physical Laboratory in England, rods of hardened steel in which could be studied from year to year the variation of some of the properties which depended on the state of hardening, and required at the same time accurate investigations on, for example, their exact lengths and their electrical resistances?

Mr. ISAAC E. LESTER (Birmingham) wrote that the importance of Sir Robert Hadfield's paper could only be fully recognised by those

who had spent much time among the native workers in India and to whom it would prove of absorbing interest. Sir Robert deserved well of the Institute for the time, trouble, and expense he had bestowed upon such an excellent treatment of the subject. His researches and deductions from archaeology and analysis with the further aid of micro-examination were extremely valuable, but at the same time it was his (Mr. Lester's) humble opinion that it was not always possible to gauge a process by the product. He had had the honour, in his Presidential Address before the Staffordshire Iron and Steel Institute in September last, of dealing specifically with "Indian iron," of which subject he had made a rather close study during over four years' residence in India. In establishing steel manufacture in India on an economic basis and seeking successfully to develop some of the great natural resources of India, it was desirable to evolve some method, suitable alike to the labour and climatic conditions, which would result in the blending of the best possible material with native labour, and the production of steel for all purposes equal or superior in all respects to British manufacture for extensive use in India. It was thus that he became closely acquainted with the native methods of manufacture, and realising that Indian iron and steel were of such world-wide renown, his conception was, that could iron and steel be produced in bulk economically, under native conditions, such an industry might be for all time established. In the pursuit of that aim he had closely studied the development of the process from its remote origin (when the elements were fitfully employed with the crudest possible appliances), and as far as recorded, traced it up to the present practice on a native basis. From such an examination an insight was gained as to the primitive practice and novel methods employed by the Loha or iron worker.

An explanation of the superiority of Indian iron was sought for in the method of its manufacture and its after treatment, and in the main, in treating of that subject in his paper, his object was, if possible, to correlate and deduce from everyday practice, treatment, and results the exact methods which had been in use for very many centuries.

Briefly stated, his treatment of the subject had been synthetical, dealing specifically with iron (where it was possible to discriminate, which he admitted was difficult), and with the intention of dealing later with the specific manufacture of steel. He had pointed out that "The low carbon content (in iron and steel) is always variable, and with even 0.4 to 0.5 per cent. (unhardened) the quality is unsurpassed in malleability and ductility." "The principle involved is the same (in the refining of the iron sponge), viz. the uniting or fusing of very small grains with other or larger grains or shots of steely iron content in the sponge by kneading or balling together in a reducing atmosphere through an imperfect covering of slag." "The operative ability of the smith makes or mars the quality of his product."

"An expert smith or Loha mistree, who ranks higher than a smelter producing the sponge, is aware of the difference between

very hard steely iron and a softer one, and by careful selection of portions of his refined product will make an iron (although containing carbon) fit for hammering out in the cold to a dished hollow shape (as per specimen cooking vessel) or into an axe or kuttar, as per example also."

"The carbon content in the bowl is 0.092 per cent., manganese a trace, and silicon 0.027 per cent., and in the axe 0.4 per cent. and 0.6 per cent. respectively of carbon, which near the eye is only 0.1 per cent. carbon."

From that method he thought it was quite safe to conclude that it was not necessary that the method of cementation mentioned by Sir Robert Hadfield should have been known by the native, who for long ages had handed down by caste the peculiar methods of manufacture and treatment, and had met his small, yet exact, requirements by judicious treatment of the crude grains of iron and steel.

He had in his possession edged tools and knives, which were very old, and had undoubtedly been made of carefully selected material, and where in some cases it was possible plainly to see, by etching, the fusing or weld lines where the softer backing supported the harder cutting edge. Moreover, he thought there was much point in the native practice of manufacturing articles of that kind, for it was recognised by the native that a much better blow was effected without the risk of shattering the weapon or tool, which, if of hard steel throughout, was more liable to breakage or splitting.

With regard to hard cutting tools such as were mentioned as having been in use in Egypt, he (Mr. Lester) thought that such tools were steel, possibly of Indian manufacture, and such as were to the present day used by native quarrymen in India, who "get" the hardest rock by letting the round-shaped bar fall through their hands continually on the same spot, which when hollowed was rinsed of powdered rock by washing out with water. That served to keep the end of the bar or blunt chisel cool, and to present a fresh striking surface each time. The process was a slow one, but sure of results. He sincerely trusted that an examination of the Delhi "lat" would be possible, for of one thing he felt quite assured, namely, that the column was of iron containing carbon, which had been produced in some one of the furnaces and by one of the methods he had described. He also believed that the analysis would vary throughout the whole length, although, generally speaking, the carbon would not be high and much slag would be found to be enclosed.

Dr. W. M. FLINDERS PETRIE, F.R.S. (University College, London), sent the following interesting communication with reference to the ancient metallurgy of iron and steel in Egypt:—

Iron was known in Egypt from the middle of the prehistoric civilisation (about 6000 to 7000 B.C.) onwards, being well authenticated in the subsequent ages of the IVth, VIth, XIIth, XVIIIth, XXth, and XXVth dynasties. It was only found sporadically, and was never in general use until about 500 B.C. That strongly showed

that native iron was the source, and not an artificial product by reduction, which would have been repeated. The pure hematite beds, carboniferous strata, and immense basalt flow of Sinai furnished a likely source for native iron.

The first general group of iron tools belonged to the time of the Assyrian invasion of Egypt (666 B.C.), and was found at Thebes. When magnetised they mostly retained permanent magnetism, showing that they were hardened to some extent. They were now at the Manchester Museum.

An entirely different question was that of the Egyptian methods of stone working. From the absence of iron tools until late times it seemed clear that iron was not used. For soft stones, copper and bronze chisels were certainly used, as Professor Petrie had found them in Sinai, where there was no stone but sandstone. For hard stones hammer dressing with stone discoid hammers was universal; the hammers were very commonly found. For fine work, sawing and tube drilling with emery was the regular method. The examples of such work in granite were common, with saw-cuts over 7 feet long. There was strong evidence that fixed cutting points were used, as well as loose powder. For complex forms, as sculpture and raised signs, a hand graver of copper, fed with emery, was used.

REFERENCES.

Iron in general.—"The Labyrinth," by Petrie, Mackay, and Wainwright. Just being published.

For Assyrian iron tools.—"Six Temples at Thebes," by Dr. Flinders Petrie. Plate XXI.

For methods of stoneworking.—"Pyramids and Temples of Gizeh," by Dr. Flinders Petrie. Plate XIV. ; and "Arts and Crafts in Ancient Egypt," chapter vii.

Mr. VINCENT SMITH (Oxford) wrote giving a few references which he hoped might be of use to Sir Robert Hadfield. Sir Robert referred to "the ingenious artist, Mr. Stodart," but had not apparently noticed a paper by that gentleman, entitled "Brief Account of Wootz or Indian Steel," by J. Stodart (undated, but early in 19th century), to be found in the quarto volume of "Pamphlets," vol. cccclxxxix., in India Office Library (printed Catalogue, p. 524). The account of the ruins of Sigiriya, as published in the Royal Asiatic Society's *Proceedings* for 1876, had been supplemented by the more recent reports of the Archaeological Survey of Ceylon, especially Mr. C. H. P. Bell's Report for 1905 ("Sessional Paper," xx., 1909), and also his (Mr. Vincent Smith's) new book, "A History of Fine Art in India and Ceylon."¹

The Iron Pillar at Delhi was referred to on pp. 130 note and 174 of that work. As to the early use of metals in India, references might also be made to Mr. Smith's papers, "The Copper Age and

¹ Clarendon Press, Oxford, 1911, quarto, 386 illustrations.

Prehistoric Bronze Implements of India." ¹ and the "Supplement" to above, ² illustrated (March number).

Professors Flinders Petrie and Currelly dwelt with the subject of Egyptian tools in "Researches in Sinai," Murray, 1906, p. 161. Professor Petrie found copper chisels at Sinai. In a lecture (Nov. 1908) he said that copper could be hardened by (1) use of arsenical ore; (2) imperfect refining, leaving some oxide; or (3) long-continued hammering; and referred especially to Egypt.

The alleged Gujarati derivation of Wootz was highly improbable.³

The use of iron did not seem to be alluded to in the *Rig-veda*. The oldest "Vedic literature" covered many centuries. Mr. Smith was disposed to derive the knowledge of iron in India, at least in Northern India, where a "copper age" existed, from Babylonia.⁴

The civilisation of Southern (Dravidian) India was probably introduced by sea, perhaps from Babylonia also. Quantities of ancient iron implements occurred in the megalithic monuments and prehistoric cemeteries. As to the prehistoric remains, there was a select list of references in the chapter by Mr. Smith on "Prehistoric Archaeology."⁵ The subject of the early use of iron in India was a big one. Southern India did not seem to have had either a copper or a bronze age.

The Hindu form of Delhi was "Dilli." The derivation was unknown. The iron girders at Konārak (not Puri) were of the thirteenth century. They were made up in a clumsy manner by defective welding.

Professor T. TURNER (Birmingham) wrote that the subject of the production of iron by primitive processes in various parts of the world had interested him for many years. A few additions might be made to the bibliography given by Sir Robert Hadfield, especially in relation to the manufacture of iron in India and the process by which the Delhi pillar was produced. He had himself contributed a paper to the Institute on the production of wrought iron in small blast-furnaces in India,⁶ and a few years later Syed Ali Bilgrami gave a very interesting description of the iron industry of Hyderabad.⁷ While he (Professor Turner) was preparing the paper above-mentioned, he was informed by Mr. John Harris, who was a very competent observer, that on the sides of the Delhi pillar the marks of welding were plainly to be seen, showing that the mass was built up by welding on discs of iron. In the discussion on the paper the late Mr. Charles Wool of Middlesbrough, who would still be well remembered by many members of the Institute, and who was in India at the time of the Mutiny, stated that he believed that he was the

¹ *Indian Antiquary*, Bombay, 1905, pp. 229 fol., with a map, 5 plates, and 4 woodcuts (October number).

² *Ibid.*, 1907.

³ Yule and Burnell, "Glossary" (Hobson-Jobson) 2nd ed., by Crooke.

⁴ "Early History of India," 2nd ed. (Clarendon Press, 1908), pp. 2, 143 n.; also pp. 35 note and 356.

⁵ *Imperial Gazetteer*, vol. II. (Clarendon Press, 1908).

⁶ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 162.

⁷ *Ibid.*, 1899, No. II. p. 65.

first to point out, presumably about 1858, that the pillar was of wrought iron, and that it had been made by welding small pieces into the end of a shaft or bar. Whether Mr. Wood published his views at the time, he (Professor Turner) did not know, but it was certain that so early as 1871 Mr. Robert Mallet had stated: "We are thus obliged to consider that this pillar is not a casting but a huge forging in . . . wrought iron," while shortly afterwards Mr. G. M. Fraser contributed a long letter to the *Engineer*, vol. xxxiii. pp. 19, 20, in which the fact is very clearly expressed that the pillar was made of malleable iron and produced by welding together successive lumps or "Mootees" of wrought iron which had been produced in a primitive blast-furnace. Reference might further be made to an interesting paper on the "Very Early Use of Iron," by St. John Vincent Day,¹ in which much attention was given to Indian iron manufacture and particularly to the Delhi pillar, which was drawn and described in detail. A quotation was also made from the "Archaeological Survey Report to the Government of India for 1861 to 1862," in Act 65 of which Col. A. Cunningham referred to the pillar as being a solid casting of mixed metal, the whole length of which was not less than 60 feet and the weight upwards of 17 tons. As those erroneous statements led to considerable controversy and inquiry, in which the Iron and Steel Institute took part, it would be interesting to know how they could be reconciled with the remarks attributed by Sir Robert Hadfield to Sir Alexander Cunningham on page 154 of the paper under discussion, and where it was correctly stated that the pillar was upwards of 22 feet in length (above ground) and of solid wrought iron, welded together. If the errors which unfortunately crept into the earlier reports were corrected between 1862 and 1865, it would be interesting to have the fact placed on record.

SIR ROBERT HADFIELD, in replying, expressed his obligation for the various interesting communications on his paper. Matters of that nature, however, did not leave much room for discussion. He thanked Dr. Arnold for his valuable statement, which would be found to be fully borne out by those who could find time to pay a visit to the British Museum and see the valuable collection of specimens of ancient iron weapons. Professor Benedicks sent some interesting statements with reference to remarks by other investigators. He (Sir Robert) would point out, however, that in his paper he had, as far as possible, tried to confine his research to specimens of definite antiquity.

If the present paper had brought out nothing more than the very valuable contribution of Dr. Cushman, he would have felt repaid for his labours. The question of corrosion dealt with by Dr. Cushman was of great importance. To find that the specimens upon which the author had experimented and dealt with in his paper threw light upon the interesting problem of corrosion was indeed most satisfactory.

The excellent suggestion made by Professor H. Le Chatelier as to depositing specimen rods of unhardened and hardened steel at the

¹ *Proceedings of the Philosophical Society of Glasgow*, 1872, vol. viii., No. II, p. 235.

International Bureau of Weights and Measures in France, and at the National Physical Laboratory in England, should certainly be followed up. The author would also suggest the National Bureau of Standards in the United States and the Reichsanstalt in Berlin as suitable places. No doubt in time very valuable evidence would then be accumulated with regard to the various physical properties of steel which depended on the state of hardening.

With regard to the concluding portion of Professor Turner's remarks, there was not space to quote in full the Cunningham reports, but the references to those reports would show that the quotations made by the author represented the erroneous belief prevailing at that time.

FURTHER NOTES ON THE EARLY USE OF IRON IN INDIA.

COMMUNICATED BY H. G. GRAVES (UNITED SERVICE CLUB, CALCUTTA)

AT the time when Sir Robert Hadfield was describing, before the Royal Society of London, the "Early Use of Iron in Ceylon and in India," the present author was at Konarak, where he made notes on the subject of the big iron beams found in that locality, with the intention of sending a description of them to the Iron and Steel Institute. The two largest are, approximately, 35 feet long by about 8 inches square, and 25½ feet long by 11 inches square, respectively. The latter beam has one end broken off, so that its original length is uncertain, but the piece, as it now lies, weighs about 9000 lbs. The end shows its method of construction by welding up of blooms, and further particulars in this connection are given in this note.

In these circumstances, the author felt that the accompanying further notes relating to the early use of iron in India might be of interest to members of the Iron and Steel Institute, and of no less interest to Sir Robert Hadfield himself, as a supplement to his own valuable paper.

There are three instances in India of very large forged iron columns and beams which can be ascribed to a period prior to A.D. 1000. The exact dates of their production are not ascertainable with any approximation to certainty, and as other details of their size are not readily available, the following notes have been written.

The best-known example is the iron column at Delhi. Roughly, it is 23 feet 8 inches high, and ranges in diameter from 16½ to 12 inches. Its weight is estimated at about 6 tons. The column at Dhar, in Central India, which is now broken into three pieces, is however larger, being about 43 feet long

and square, to octagonal, in section of 11 to 10 inches square. Its weight may be taken as 7 tons, or a ton heavier than the Delhi pillar. The third, and least known, is at the so-called Black Pagoda at Kanarak or Konarak in Orissa, possibly the most noteworthy of all, as the pieces are so numerous, and all are of very considerable size. The largest is a rectangular bar,

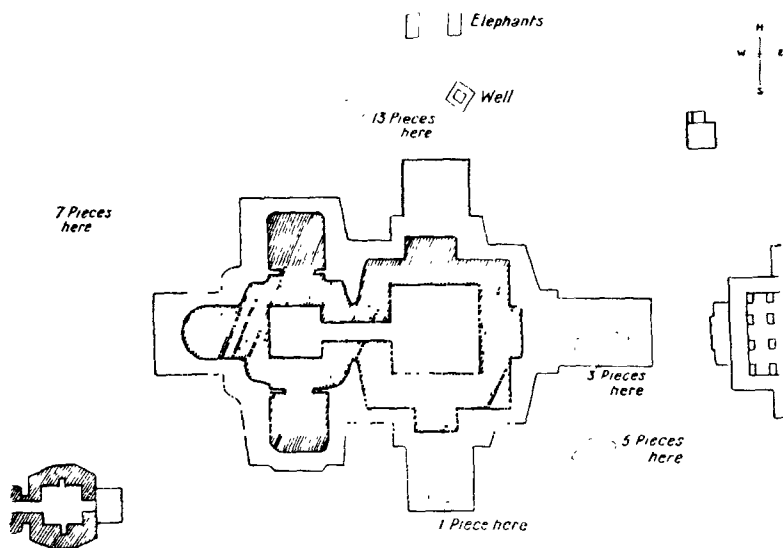


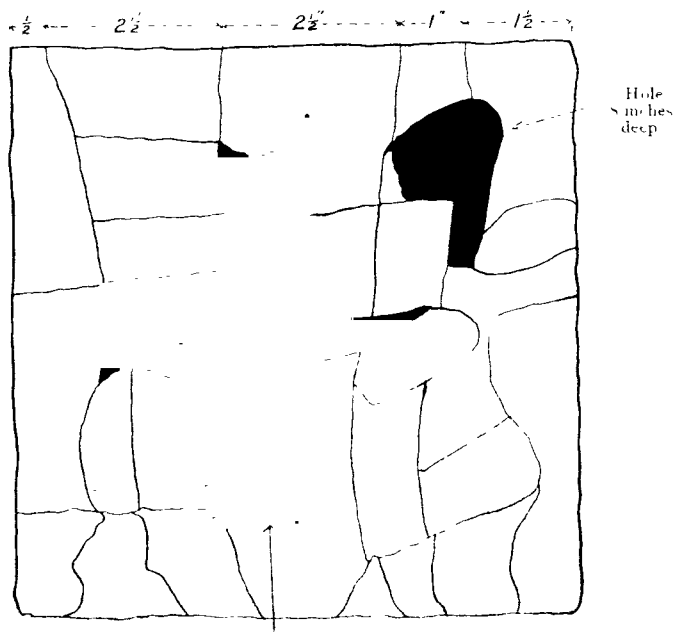
FIG. 1.—Plan of Temple at Konarak

23½ feet in length and 11 by 10½ inches in section. It is part only of a longer bar, one end being broken off and missing, but in its present state it must weigh over 4 tons. The next largest is an unbroken rectangular bar, 35 feet long and 7 to 7½ inches square, weighing about 6000 lbs. Altogether, scattered around the temple, are twenty-nine pieces in all, none of them less than 5 inches square in section. Some of the pieces are only 5 or 6 feet in length, and, could they be matched, it would probably result in not fewer than twenty complete beams.

THE IRON PILLAR AT DHAR.

A full and accurate account of the iron pillar at Dhar is given by Mr. Henry Cousens on pages 205 to 212 of the

Annual Report, 1902-3, of the Archaeological Survey of India, issued in 1904 from the Government Press at Calcutta. From this Report, which is illustrated by views of the four faces of the pillar, the following details are taken. The pillar is in three portions, which are now scattered in the town. The longest portion is 24 feet 3 inches and is square in section throughout; the second is 11 feet 7 inches, of which 8 feet



Dark part, hole several feet deep—cinder found in this

FIG. 2.—Fractured End of Iron Beam at Konarak.

Note.—Right-hand bottom corner very cindery and irregular
Left-hand vertical side particularly good metal.

6 inches is square and 3 feet 1 inch octagonal; and the third piece, 7 feet 6 inches in length, is of octagonal section except for a circular section at one end, 8 inches deep. The octagonal section is very irregular in form. The total length is 43 feet 4 inches, and the average section is $10\frac{1}{4}$ inches square. One end of the longest piece, which was originally the base, is slightly bulbous, being 11 to $11\frac{1}{4}$ inches wide at 2 feet from

the end, while the rest measures $10\frac{1}{4}$ to $10\frac{1}{2}$ inches. Although the length is given as 43 feet 4 inches, it is quite possible from consideration of the proportions and sizes of the octagonal and square portions, that there is a fourth and missing piece, which would bring the total length up to 50 feet.

An inscription, dated in the forty-fourth year of Akbar's reign, A.D. 1600, was engraved on the fallen column, so that it

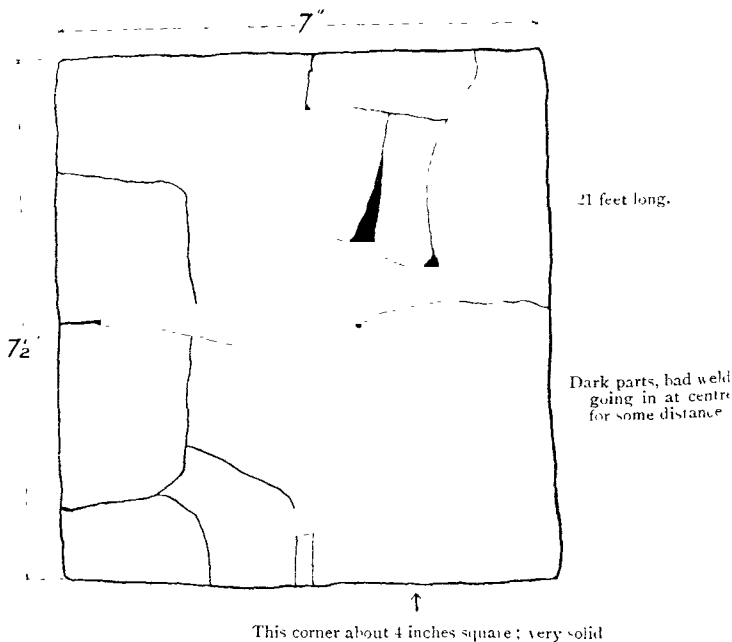


FIG. 3.—Fractured End of Iron Beam at Konarak.

would be upside down if the column were re-erected. Inscriptions earlier than this, yet later than the fourteenth century, had been engraved the right way up near the foot of the column before it fell.

Upon the masonry basement, where the larger piece reclines, are three great rock boulders which were bound together by iron bands, and had a socket in the top 20 inches deep, in which the foot of the pillar was gripped. The iron bands securing them passed through them horizontally, and their pressure

was spread over the boulders by vertical flat iron bars, inserted at intervals under the bands in slots cut for the purpose.

One curious thing about all three sections is the presence of a number of holes at intervals varying from $1\frac{3}{4}$ to 3 inches in depth, and in diameter about $1\frac{1}{4}$ inch. They run up each

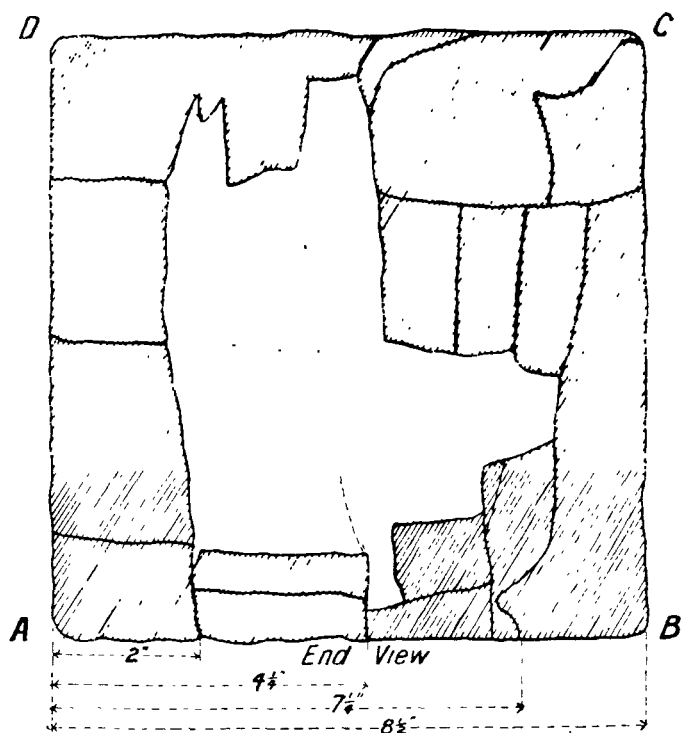


FIG. 4.—End View of Beam shown in Fig. 5.

of the four sides of the square shaft and corresponding faces of the octagon. They are too far apart and too irregular to have been used for climbing purposes. Mr. Cousens suggests that these holes were intended to hold tommy bars for turning the mass while it was being forged. One hole still retains, immovably jammed in it, the broken end of a bar, while all the rest are empty. At the bottom end is a hole 3 inches deep, which probably fitted over a socket-peg during erection.

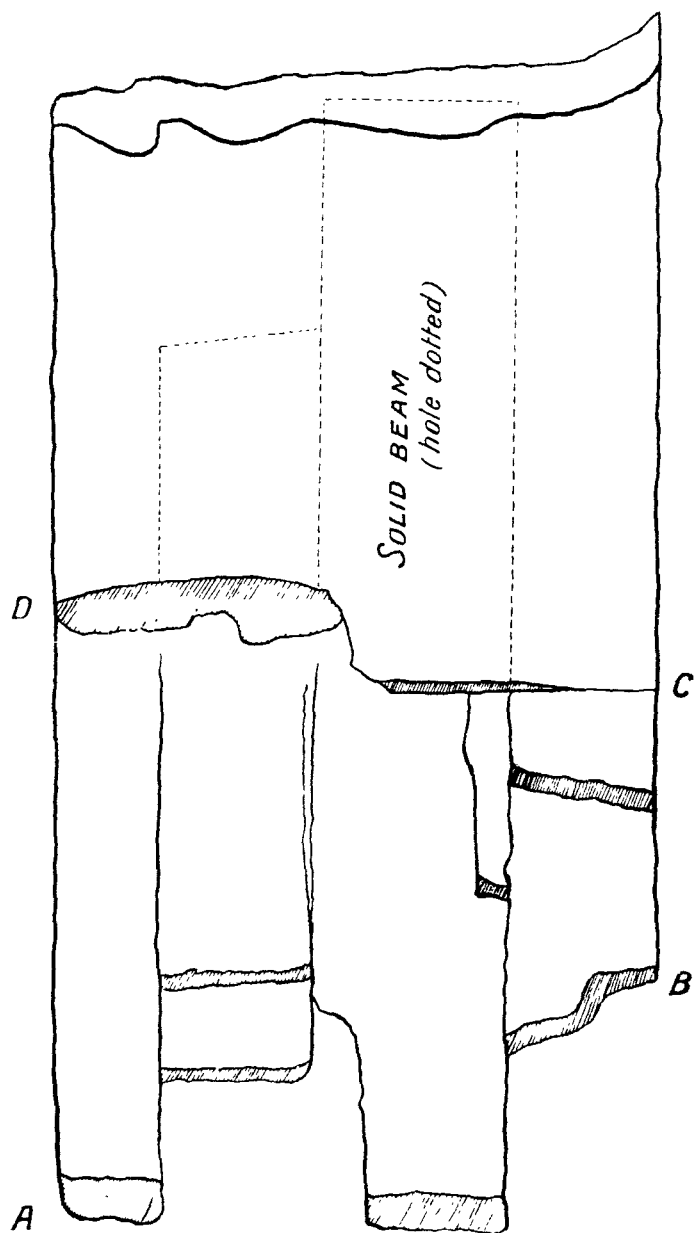


FIG. 5.—Plan of Beam shown in Fig. 4.

The very meagre details of the history of this pillar give no clue as to who caused it to be made, or for what purpose it was forged. Most probably it was designed to carry an image or symbol on the circular neck at the top, and it was set up before a temple as a special gift, or as a "jayastambha" or column of victory. The form, with a square base and octagonal upper portion, is analagous to columns of the Gupta period (date A.D. 320 to 480), but there are no original

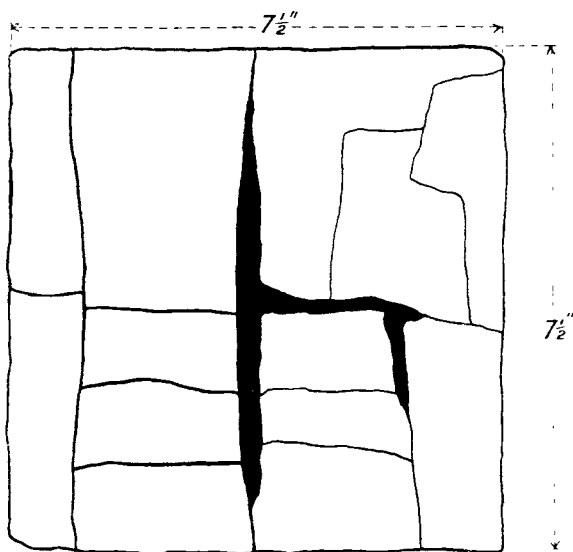


FIG. 6.—Fractured End of Iron Beam at Konarak.

inscriptions on the column itself, or sufficiently definite references elsewhere, to give a basis for anything but the vaguest conjecture.

The pillar was probably entire in A.D. 1304, when it stood at Mandu, some 22 miles from Dhar. It was thrown down by the Mohammedans and broken in two pieces. After 100 years the larger piece was brought to Dhar about 1405, where it was erected, but knocked down and again broken into two pieces about 1531. Even these dates are somewhat uncertain, and both these and later accounts vary considerably in details.

THE IRON BEAMS AT KONARAK.

Although the largest mass of iron at the Black Pagoda at Konarak was probably smaller than the Delhi pillar, yet the place is specially remarkable because of the number of large beams still existing and lying scattered around the building.

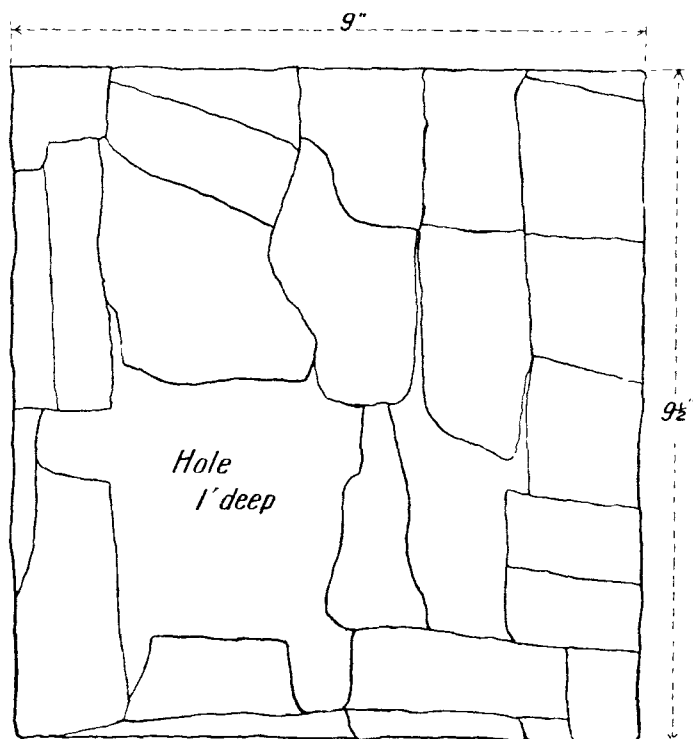


FIG. 7.—Fractured End of Iron Beam at Konarak

This is hardly the place in which to enter on a disquisition as to the age of the temple. That matter has been hotly discussed from time to time. Fergusson, relying on the comparative architecture, ascribed it to the latter half of the ninth century, but others have placed it as late as A.D. 1241. The latest and fullest description of the temple is given by Bishan



FIG. 8.—Photograph by J. W. Meares of two iron beams lying on the portico of the Black Pagoda at Konarak, Orissa. The one against which the walking-stick stands is deeply weathered as if by sand-blast except at the ends. The central line are holes with intervening thin bits of metal bridging the sides of the hollow all down the centre of the beams, into which a stick can be thrust.

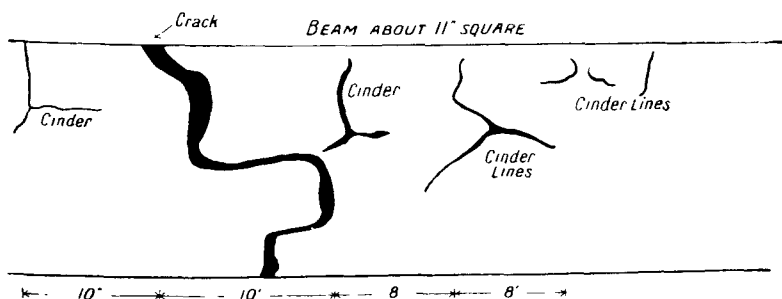


FIG. 9.—Top of Beam lying near handle of walking-stick in Fig. 8.

Swarup in a work entitled "Konarka, the Black Pagoda of Orissa," published by the Government of Bengal in 1910. This work is illustrated by plans, elevations, and photographs. He inclines to the middle of the ninth century for the inception of the building, and the completion of the later parts in the thirteenth century. In his opinion the temple was completed, and its fall was caused mainly by the removal or collapse of the heavy "amla" forming the top of the corbelled-in roofs, which then gradually sank inwards and fell.

The temple lies some 20 miles from Puri, which is twelve hours by rail from Calcutta. It can only be reached across the loose sandy dunes and plains in a *pulli* or on horseback. Riding ponies are not available in Puri except by special arrangement. Near the temple there is a small rest-house, but very few supplies are available from the small adjacent village. The traveller has to rely entirely upon what he brings with him, so that at the time of the author's visit it was impossible to get samples of the iron. Even the camera failed to produce more than one picture, and that not of the best, so reliance is placed on rough sketches made by the author and his friend, Mr. J. W. Meares.

Originally the beams were used as supports under the lintels of the doorways and to expedite the corbelling-in of the roof. On a very much smaller scale similar beams can now be seen in the so-called garden temple at Puri which is one of those accessible to the non-Hindoo public. Full dimensions of these beams are given below.

The Konarak temple has been closed up and filled in with masonry and sand to prevent further falls, so it is not possible to say exactly where the beams were originally placed and whether there are any left *in situ*. Nearly all the beams have been broken by the fall. Some are very heavily rusted, but many are scarcely affected, or have a very thin and closely adherent coating. One beam which is now lying on the portico, has evidently been partially exposed for a long period to the sandy winds, for it is worn down at least an inch in depth, enabling the defective structure to be seen.

This particular beam and the fractured ends show very

clearly that the method of manufacture was by welding up small blooms, generally about 3 or 4 lbs. in weight. The blooms are commonly 2 by 1 inch in section, but occasionally 2 by 2 inches or 1 by 1 inch, and a common length is about 6 inches. In a few cases the blooms may have been larger or the welding was done more effectively. The rough sketches appended to this paper show with fair accuracy the relative sizes and disposition of the blooms in several beams. Many

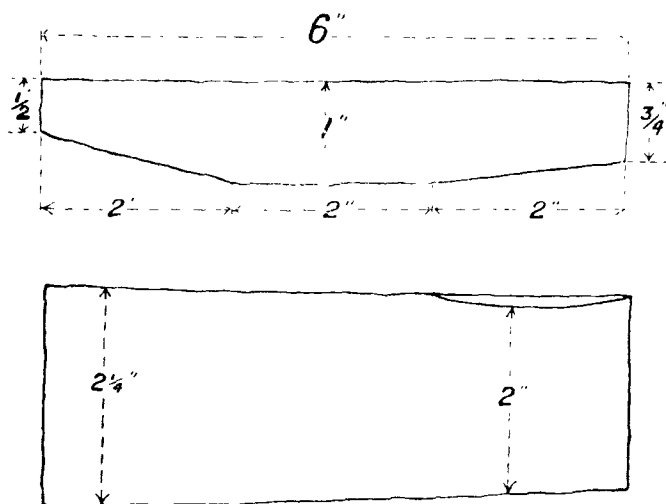


FIG. 10.—Bloom in Beam at Konarak.

of the broken ends show the existence of irregular and sometimes uniform cavities. It is possible to thrust a stick down some of them to a depth of 7 or 8 feet, and the sand-blasted specimen shows a cavity nearly the whole length of the beam. From these hollows bits of cinder can be raked out.

The author regrets that he is not a sufficiently good smith to say definitely how the blooms were welded *in situ*, but it seems more than likely that the blooms were welded singly, or possibly two or three at a time, on to the end of the work. In some places, however, it looks almost as if the blooms were welded together in strings to form short bars, which were then in turn welded into place. Either method

and the large size of the beams would account for the very defective interior welds. No care has been taken to make the blooms break joint, either longitudinally or in cross-section, though the longitudinal welds generally show as lap rather than butt welds. Externally the beams are well finished, though the cracks and lines show where joints were.

In the illustrations to this note, Fig. 1 is a rough plan, reproduced from Bishan Swarup's book, of the temple at Konarak, on a scale of 126 feet to the inch, to show where the pieces of iron beams are now lying. Until five or six years ago they were buried by sand drifts, and were moved during the excavation and repairs. Figs. 2, 3, 4, 6, and 7 are end views of fractured beams, showing roughly the disposition of the welded blooms and the defective welds. The lines of the welds are perfectly clear, and often show more than traces of cinder. Fig. 5 is a plan view of the broken end shown in end view in Fig. 4, the corresponding corners being marked A B C D in the two views. Fig. 8 is the reproduction of a photograph on the portico (where three pieces are marked on the plan, Fig. 1) showing two complete beams. The upper beam is partly cracked across near the handle of the walking-stick. It was covered with a thin but closely adherent layer of oxide that almost defied removal by scrubbing with sand. Partly polished, it showed cinder or weld lines as illustrated in Fig. 9. Although some of the beams were so heavily rusted that flakes half a foot square and half an inch thick could be scaled off, most of them were only superficially oxidised. Apart from defective welds, the beams are solid masses of metallic iron, that, for purposes of sampling, would defy anything short of explosives, an oxyacetylene blowpipe, or much strenuous work with a hack-saw. The bloom, shown in elevation and plan in Fig. 10, was so firmly attached that it was impossible to remove it in the absence of tools, but may be taken as typical of those used in all the beams.

The beams are nearly all of uniform size, and square in section from end to end, varying not more than half an inch except at the extreme ends. The greatest variation in size is in one beam, which is 7 inches square at one end and increasing to 9 inches square at 3 feet from that end. It is 14 feet

long, but the end which is broken off has a section of 8 by $8\frac{1}{4}$ inches. It is only in this one beam that there is such a considerable variation in section, and the author is strongly of the opinion that there is no indication that the makers had any idea of using a greater depth of section in the centre of the length or of disposing the metal to attain its proper strength. The beams are simply square bars, so imperfectly welded that they could not have supported very much more than their own weight. All the same they are wonderful productions, into which labour must have been poured like water, irrespective of cost.

The annexed list, made by Mr. N. C. R. Chaudhuri, the district engineer at Puri, shows extensive use of iron in the Gundichabari or Garden Temple at Puri. This is the temple where the images of Jagganath (Juggernaut) and his brother and sister, Balabhadra and Subhadra, are taken on three cars for ten days in June or July each year. The list shows the dimensions of 239 pieces, ranging up to 17 feet long and up to 6 by 4 or 5 by 5 inches section. Apparently there is a similar extensive use in the main temple, which is not accessible to non-Hindus. It is said that the false roof in the tower is supported by iron beams, one of which, about 20 feet long, fell in 1877 or 1875.

The garden temple is probably contemporaneous with the main temple, which was built not later than the first half of the twelfth century, and possibly earlier. The surrounding walls, in which the beams are also found, are contemporaneous, but the main temple certainly had considerable additions up to the fourteenth or fifteenth century. Whether these contain iron or not the author is unaware, nor does he know whether the great temple at Bhubaneswar (closed to non-Hindus), between Cuttack and Puri, contains iron. It was built probably in the eighth century, and from its size and style it would appear to have beams. The smaller temples at Bhubaneswar which the author has seen, of somewhat later date, do not contain iron to the best of his recollection; but if they did they would not be big pieces. Nor do the temples at Khujaraho, or Khajuraho, in Chhatarpur State, Central India (also seen by him), which are still later but of the

same style (see Fergusson's "Indian Architecture"). In any case it may be assumed that from the eighth to the twelfth century, and possibly one or two centuries before and after, in the Orissa districts there were smiths capable of forging large masses of iron in quantities.

IRON BEAMS AT THE GUNDICHĀ-BĀRI OR GARDEN TEMPLE AT PURI.

1. *At the Lintels of Doors in the Outer Compound Wall.*

	No.	Length		Breadth	Height
		Ft.	In.	Inches.	Inches.
Back door	1	10	5	3	4
	2	7	7	3	4
" "	1	9	8	3	4
	1	8	5	3	4
Front "	2	11	4	5	3
	2	9	8	5	3
" "	2	8	0	5	3
	1	12	6	5	3
		<u>12</u>			

2. *At the Lintels of the Outer Doors of the Garden Temple.*

	No.	Length.		Breadth.	Height.
		Ft.	In.	Inches	Inches.
Door	2	5	0	5	3
	2	6	7	5	3
	2	7	6	6	4
" "	2	9	8	6	4
	2	6	8	6	4
	1	5	0	6	4
" "	1	5	0	3	4
	1	6	8	3	4
	2	5	0	4	3
" "	1	5	0	4	4
	2	4	2	4	4
	2	6	9	5	4
" "	2	5	0	5	4
	2	9	8	5	5
	2	7	6	5	3
" "	2	6	8	4	4
	2	5	0	5	3
	2	6	4	4	3
" "	2	5	0	4	4
	2	6	4	4	3
	2	5	0	3	3
		<u>38</u>			

3. *At the Lintels of the Inner Doors of the Garden Temple*

	No.	Length.		Breadth.	Height.
		Ft.	In.	Inches.	Inches.
Door	1	9	0	5	5
	2	7	0	4	3
	3	10	3	5	4
"	2	6	3	4	3
	2	5	0	4	3
	2	7	6	4	3
"	2	5	9	4	3
	2	5	2	4	3
	2	4	0	4	3
"	2	4	7	4	3
	2	3	6	3	3
	2	5	6	4	3
"	2	4	6	4	3
	2	4	8	4	3
	2	3	6	4	3
"	2	9	2	5	4
	2	7	0	4	4
	1	10	5	5	4
"	2	8	0	3	4
	2	6	9	3	3
	1	4	9	3	2
"	1	4	9	3	2
	1	3	6	3	2
	1	4	3	3	3
"	1	4	3	3	3
	1	4	6	3	3
	1	4	6	3	3
		45			

4. *Pillar Plates (within the Temple).*

No.	Length.		Breadth.	Height.
	Ft.	In.	Inches.	Inches.
12	17	2	5	4
4	10	10	5	4
16				

5. *Beams below Temple.*

No.	Length.		Breadth.	Height.
	Ft.	In.	Inches.	Inches.
7	6	0	5	4
53	3	0	3	3
16	2	0	3	3
17	3	0	3	3
2	1	6	3	3
1	1	0	3	3
16	2	0	3	3

6. *Beams at the Corner of the Temple Room.*

No.	Length		Breadth.	Height
	Ft.	In.	Inches.	Inches
4	2	0	3	2
4	1	0	3	2
4	2	0	3	2
4	1	0	3	2
<u>16</u>				

(A) *Number of Beams at the Lintels of the Doors.*

Item 1	.	.	.	.	.	12
" 2	.	.	.	.	.	38
" 3	.	.	.	.	.	45
Total						<u>95</u>

(B) *Number of Beams below Temple, Pillar-Plates, &c.*

Item 4	.	.	.	.	.	16
" 5	.	.	.	.	.	112
" 6	.	.	.	.	.	16
Total						<u>144</u>

NOTE ON SOME REMAINS OF EARLY IRON MANUFACTURE IN STAFFORDSHIRE.

BY PROFESSOR THOMAS TURNER, M.Sc. (UNIVERSITY OF BIRMINGHAM).

ABOUT a year ago, Mr. Benton, who at that time was in charge of the art classes at Bournville, and who is much interested in archæology, drew my attention to some ancient remains of iron manufacture which are met with in various parts of the districts around Birmingham, and particularly in the vicinity of the site of Little Aston Forge. The ruins of this forge are situated at a distance of rather more than a mile to the south-west of Shenstone. Its position is indicated by a cross on the map (Fig. 1).

In September 1911, Mr. Benton was good enough to accompany me on a visit to the locality, where I saw a number of lumps of iron, or "ham-bones." Some of these were in heaps, some had been used as road metal in the bye-lanes, and others were scattered about in various places. I understand from Mr. Benton that a few years ago there was a heap containing many tons of such iron, but this had been removed since his previous visit.

Mr. Benton informs me that "ham-bones" were also certainly produced at the Old Witton Forge, near Birmingham. The site of this forge is now part of Kynoch's Works, which include a corner of the old Roman camp at Perry Barr. Sandwell Mill, on the river Tame, where it is crossed by the lane from Newton to New Inns, is another locality, near Birmingham, where "ham-bones" are to be seen.

A sample in excellent preservation was found in the farm-yard of Mr. Grundy near Little Aston Forge, and he was good enough to forward it to the Metallurgical Museum of the University. I afterwards requested Mr. A. S. Keep to make further inquiries into the subject, and the result of these inquiries are incorporated in the following observations.

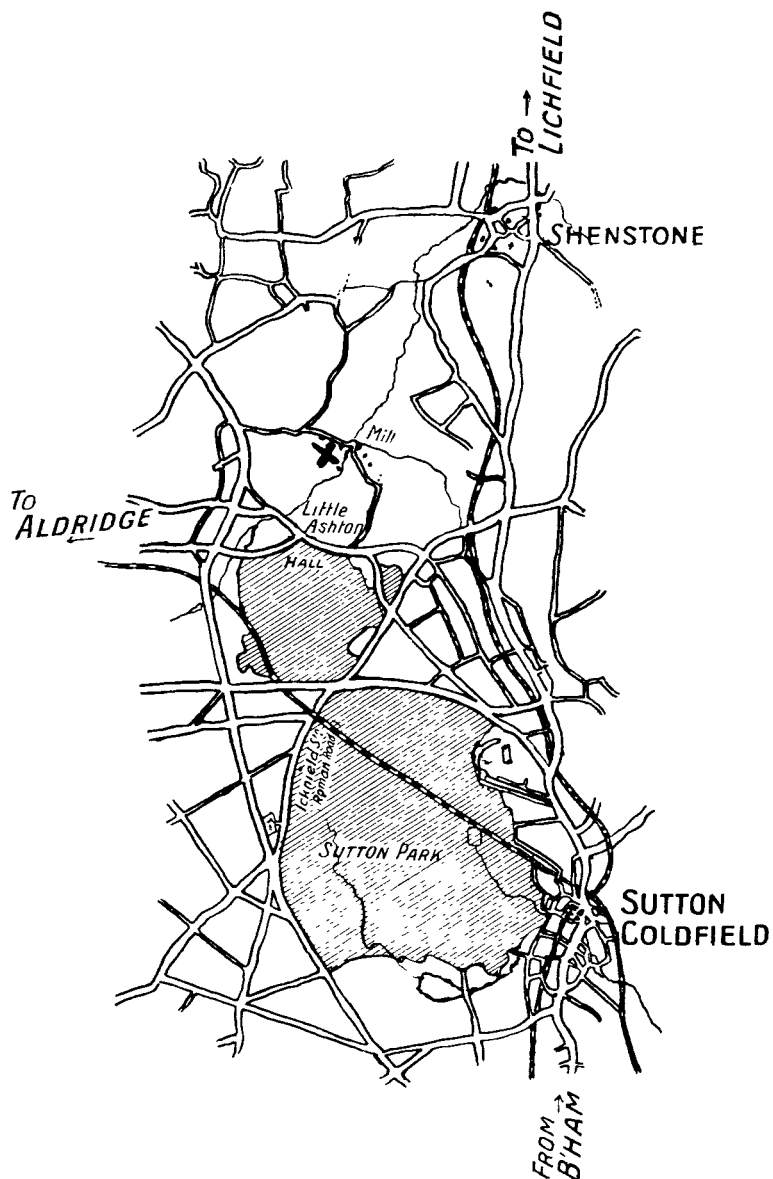


FIG. 1.

Although iron was undoubtedly produced in Staffordshire on a limited scale at a much more remote period, the history of the iron trade in the county appears to have begun with the dawn of the seventeenth century, or say half a century prior to the work of Dud Dudley. It has, however, been conjectured, from the scoria at West Bromwich and other places, that Staffordshire was the seat of the iron trade in the time of the Romans.

It is of course well known that the Romans conducted iron smelting on a very large scale in the Forest of Dean and other localities, and it is stated that iron was also smelted at Worcester, but the ore was probably brought from Coalbrookdale. Iron was smelted at Uttoxeter in the thirteenth century, and this was possibly in a survival of a very early furnace. Iron was also made at Cannock Forest in 1588. In 1560 a decayed forge with a chafery existed at Little Aston, near Shenstone, but there does not appear to have been a furnace there. It is with this ancient forge that we are at present interested.

As previously stated, around the site of this old forge, for a considerable area, large quantities of metallic iron have been found, the total amounting to hundreds of tons. The occurrence of these lumps of iron are so frequent as to be a source of trouble to the ploughmen. The lumps or pieces are all approximately of the same general shape, and vary in weight from about 20 lbs. to half-a-hundredweight or more. When perfect, each has a round or basin-shaped lower surface and a level top, with a projecting piece somewhat of the nature of a handle. From their peculiar shape they are known locally as "ham-bones," a name which aptly describes their appearance (Fig. 2).

Samples were taken from several of these "ham-bones" for the purpose of analysis. The metal drilled easily, and the turnings were dark in colour and blackened the skin when rubbed on the palm of the hand. At first it was supposed that the metal was soft grey cast iron, resembling the ancient Sussex iron I have elsewhere described,¹ but it was observed that the blackening of the hand was different in

¹ *Journal of the Iron and Steel Institute*, 1903, No. 1 p. 295.

character to that noticed with grey iron, as there was an absence of the characteristic plumbago polish commonly produced by the graphitic carbon.

The analysis gave unexpected results, the composition being as follows:—

Analysis of "Ham-bone" from Little Aston.

	Per Cent.
Graphitic carbon	nil
Combined carbon	0·31
Silicon	0·05
Phosphorus	0·31
Sulphur	4·93
Manganese	nil

It will be observed that the sulphur is extremely high, so



FIG. 2.—Photograph of "Ham-bone" from near Little Aston, with slag on the upper surface. Scale about $\frac{1}{4}$.

high in fact that considerable difficulty was at first met with in connection with the estimation. On attempting to dissolve in *aqua regia*, in the ordinary way, globules of sulphur were liberated and floated to the top of the liquid. Ultimately it was found best to treat the turnings with bromine and hydrochloric acid, which dissolved the sample and gave accurate determinations.

After the high sulphur the most characteristic point to be noted in the composition is the very low carbon and silicon. The material is certainly not cast iron, and it is difficult to understand how so high a proportion of sulphur was obtained.

There is no cause for wonder that the old workers threw their "ham-bones" away.

A portion of the slag from the upper portion of a "ham-bone" was analysed, under my direction, by Mr. R. Nevill, B.Sc. The results of the analysis are as follows:—

	Per Cent.
Ferric oxide	55.54
Silica	12.05
Alumina	7.92
Lime	3.20
Magnesia	0.45
Manganous oxide	0.24
Sulphur	2.47
Phosphorus pentoxide	0.51
Carbon	13.89
Moisture	1.84
Alkalies	0.74
Not estimated and loss	1.15
	<hr/> 100.0 <hr/>

The metallic iron present was equal to 38.88 per cent. On the outside it was almost completely oxidised to Fe_2O_3 ; the interior portions contained more or less FeO . The presence of carbon, in the form of partly burned fuel, appears to indicate that the slag was not thoroughly fluid, or the carbon would have been all at or above the surface of the slag. In composition this slag is such as would be produced in a small hearth or bloomery, and not in a blast-furnace making cast iron.

In order to throw some light on the method of manufacture, a photomicrograph was prepared from a sample cut from the centre of a "ham-bone" (Fig. 3). In the photograph the white ground consists of ferrite, while the darker portions are iron sulphide with patches of pearlite. It will be noted that the enclosures of iron sulphide are largely separate from each other. A portion of the material was then remelted in a crucible and slowly cooled. The properties of the metal were thereby entirely altered, and the material was rendered sufficiently brittle to break readily with a light blow of a hammer when held in the palm of the hand. The fracture showed a beautiful dendritic structure, a photomicrograph of which is given in Fig. 4. From this it will be seen that

the brittle iron sulphide, which solidified last, is now largely present as a continuous network, and this change of structure is doubtless connected with the increased brittleness.

It may therefore be assumed that the original "ham-bones" were never really fluid, but that they were accumulations at the bottom of a furnace employed for the production or manufacture of wrought iron. The shape of the "ham-bone" also clearly suggests that they were produced in the



FIG. 3.—Photomicrograph of Iron as found, showing large quantity of Iron Sulphide collected in pools, and also some Pearlite.
Magnified 75 diameters.

small hearth or bottom of a primitive furnace, as the projecting piece corresponds with a tapping or flowing hole. Apparently as soon as the accumulation at the bottom of the furnace reached the height of the tap hole, the process was suspended. The iron rich in sulphur was doubtless more fluid than the rest of the material; it was thus separated and collected in the bottom of the furnace. The metal which so collected appears to have been much richer in sulphur than the main product, and the regulus was thrown away each time the working of the furnace was stopped or interrupted.

It is difficult to determine the date at which these "ham-bones" were made. Their period is probably at least two centuries ago, and it may perhaps have been three centuries or even more. There is, however, so far as I am aware, no evidence which would connect them with Roman workings other than the fact that they occur in the neighbourhood of well-recognised Roman roads. The original forge at Little Aston must have been of much earlier date than 1600, as

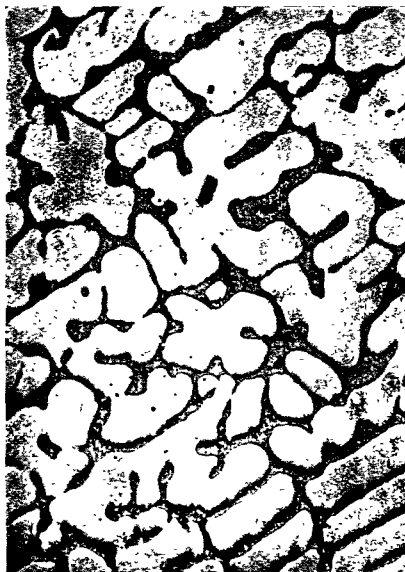


FIG 4 —Iron had been thoroughly melted and slowly cooled. Sulphide completely surrounds the Crystals of Iron.
Etched with Picric Acid. Magnified 75 diameters.

a lease, from which an extract is given below, states that the works were then in a very "Ruynous and latelie decayed" state. The "ham-bones" were, presumably produced after the reconstruction of the forge by Thomas Parkes, as there does not appear to have been an iron furnace at Little Aston, though there had been a forge, a chafery, and a hammer-mill. It is, of course, possible that the "ham-bones" may have been residues from the working of the forge or chafery, or even of some special process of which no record has survived.

In conclusion. I wish to take this opportunity of expressing my indebtedness to Mr. J. Hill, of Perry Bar, for permitting Mr. Keep to make extracts from the original lease and for his ready assistance in connection with the historical part of the inquiry.

Extract from Lease, dated September 29, 1600.

Roger Fowke of lytle Aston in Coldfeilde County of Stafford gent and Lucye hys wief of thone partie and Thomas Parkes of Wednesburye of the other partie In conson of £40 demises and leases for 21 years at annual rent of 6/8.

All that the forge Chaferie and Hamer Mill now beinge very Ruynous and latelie decayed scituate and being w'thin the lordshipe of lytle Aston aforesaid County of Stafford in a close pasture or grounde then comonlie called or knoewn by the name of Annyells or by whatsoever other name or names the same close pasture or ground ys called or knowen

And all that and those poole and pooles, fleame or fleames and trenche and trenches heretofore used as a poole or pooles fleame or fleames trench or trenches for the leadinge course Runoinge or Conveyinge of any water or waters springes streames or water courses to or for the saied forge Chaferie and Hammer Mill or any of them together with all dames stancks and bancks of the same poole or pooles and also the said parcell of land together with all that parcell or piece of the said close or pasture adjoininge and lying in lengthe betwene the said forge Chaferie or Hamer Mill and the meadowe called the Hamer meadowe at the one ende and a waie leading from a plancked bridge heretofore used for waynes horses and such lik to passe and go over parte of the said poole fleame or trenche alonge after the ende corner or a piece of the said meadowe called the hamer Meadowe at the other ende and in the breadethe betwene the poole fleame or trenche descendinge from saied bridge to the saied forge Chaferie and hammer mill on the one side and the meadowe aforesaid on the other side

And also another parte of the same parcell called Annyells from the waie aforesaid leading from the saied bridge to or right over against the next corner of the hedge or dytche bancke of the hammer meadow towards the saied bridge and from the saied corner of the same hedge or dytche of saied meadow directlie and straighte as convenientlie maie be over the olde water course now runing or descendinge into the said meadowe in and through the said close pasture to a lytle Woller or Woller bush whereof the toppe was latelie cutt of for a marke where now a stake for a marke is set and placed and from thence to another woller or woller bush (top lately cut off and stake &c.) in the hedge or an adjoininge to another meadowe

called heymore meadow now the holding or occupation of dyvers of th'enhabytants of Lytle Aston aforesaid

Power and authoritie is given by Roger Fowke and his wief to Thomas Parkes to Repaire Reedyfie or make new the said Forge Chaferie and Hamer Mill and to erecte builde make and sett upp on lande one or two fynerie or fyneries and one house or shopp commonlie called an Iron House or Iron Shoppe for the kepinge and layinge in of iron to be adjoininge to the said forge or Hamer Mill and a reasonable or necessary house of two bayes for the workmen or servants of the said Thomas Parkes to dwell in which shall work at the said forge fynerie chaferie or hamer mill or to make pooles dams stancks and to impownde heighen raise and quaire up the water and for that purpose to have digg gett and take in sufficient and convenient turves and clodds but so as not to quarrye up in parcel or meadow towards aldridge above the meere marks or bounds before mentioned.

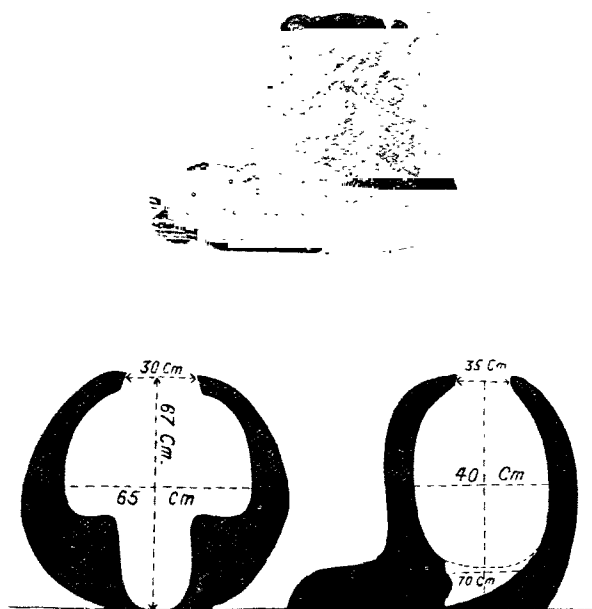
The names of Roger Fowke and Thomas Parkes, which occur in this lease, taken in connection with its date, may possibly throw light upon the origin of these curious remains of ancient iron manufacture. In the reign of Elizabeth, timber for iron-making was becoming increasingly scarce, and Acts of Parliament were passed to restrict its use. Dud Dudley was born in, or about, 1599; he was brought from Oxford in 1619 to take charge of his father's ironworks at Pensnett Chase, in Worcestershire. His first patent for the manufacture of iron with pit coal was applied for in March 1619. He states that he soon succeeded in making "much good merchantable iron"; and his brother-in-law, Richard Parkes of Sedgley, was employed to take the iron from the works to the Tower for the royal use. When his first patent expired in 1637, Dud Dudley petitioned for its renewal, and was joined in his petition by three others, one of whom was "Roger Foulkes, a Councillor at the Temple, and an Iron Master and Neighbour."¹ As the places at which "ham-bones" are found are within an hour's ride on horseback from Dudley, may it not be that they are remains of early attempts on the part of Dud Dudley and his friends or competitors to smelt iron by means of pit coal? If so it would explain the cause of the early failures of these experiments. Owing to

¹ Address delivered at the Unveiling of the Restored Memorial to Dud Dudley at Worcester, October 11, 1911, by J. Willis Bund.

the temperature of the furnace being too low, the sulphur was absorbed and retained by the iron, which was in consequence worthless. All that was necessary in order to ensure success was to enlarge the furnaces, as Dud Dudley certainly did, and perhaps with the greater heat also employ some limestone as flux. Limestone was plentiful at Dudley, but it is not found near Little Aston and its absence may have contributed to failure.

CORRESPONDENCE.

Mr. OTTO VOGEL (Dusseldorf) wrote that Professor Turner might be interested to know that he was able to give some indication of the kind of furnace in which the "ham-bones" had been formed. The accompanying illustration represented an old melting-pot (a pot for the direct production of wrought iron) found at Monchmotschewitz in Silesia, a description of which was published by the late Dr.



Wedding.¹ It was interesting to compare the longitudinal section shown in Fig. C with the illustration of the "ham-bone" in Fig. 2 of the paper. Mr. Vogel wished also to draw the author's attention to a paper by Otto Olshausen,² in which illustrations of other old melting-pots were given. Thirty-two such pots were found near Tarxdorf in Silesia, on August 5, 1908, within an area of 68 square metres. Altogether a total area of 63,000 square metres was covered with similar pots, so that, assuming they were as thickly distributed as in the fully excavated area, there must have been 30,000 to 50,000 such furnaces. In any case, the remains of an ancient iron industry

¹ *Stahl und Eisen*, December 1, 1896, p. 981.

² "Eisengewinnung in vorgeschichtlicher Zeit," *Zeitschrift für Ethnologie*, vol. xxi., 1909, pp. 60-107.

were so numerous at Tarxdorf that the courtyards of houses were paved with lumps of slag. That agreed with Professor Turner's statement where he said, "The occurrence of these lumps of iron is so frequent as to be a source of trouble to the ploughmen." The method of working was probably similar to that described by J. Morrow Campbell.¹

Professor TURNER desired to thank Mr. Otto Vogel for his interesting contribution. Though there was a considerable similarity in the two processes they did not appear to be identical, as the "ham-bones" found in Staffordshire were evidently made in a furnace in which the slagging hole was at the side and not at the bottom. It would be interesting to know the proportion of sulphur in the iron made in the melting-pots described by Mr. Vogel. Arguing from analogy, the sulphur would probably be low, while in the Staffordshire "ham-bones" the sulphur was extraordinarily high. That appeared to point to some special process or experimental period.

¹ *Iron and Coal Trades Review*, April 22, 1910, p. 605.

THE CHEMICAL AND MECHANICAL RELATIONS OF IRON, VANADIUM, AND CARBON.

By J. O. ARNOLD, D.M.I.C., and A. A. READ, M.M.I.T.

(PROFESSORS OF METALLURGY IN THE UNIVERSITIES OF SHEFFIELD
AND WALES RESPECTIVELY.)

INTRODUCTORY.

THE influence of vanadium on iron and steel was discovered by one of the authors in the steelworks of Sheffield University during a series of researches carried out from 1899 to 1902. The experiments were made on ingots melted by the Huntsman crucible process, and in the acid open-hearth furnace. The results were not published in any journal, but were copyrighted at Stationers' Hall. The influence of vanadium, *per se*, was not very marked on structural steel, but in the presence of chromium, nickel, and tungsten, the results were almost magical. On tool steel, *per se*, and with other elements, the results were startling. It was pointed out that as the carbide residue on dissolving the steel in dilute sulphuric acid contained nearly all the vanadium, this element probably existed in the form of a carbide, or double carbide: but so far no systematic research has been carried out to determine the exact condition in which vanadium may be present in steel. The present communication is a continuation of the work published by the authors in their papers on "The Chemical Relations of Carbon and Iron,"¹ "The Chemical and Mechanical Relations of Iron, Manganese, and Carbon,"² and "The Chemical and Mechanical Relations of Iron, Chromium, and Carbon,"³ and contains an account of a number of experiments made to determine:—

¹ *Transactions of the Chemical Society*, 1894, p. 788.

² *Journal of the Iron and Steel Institute*, 1910, No. 1. p. 169.

³ *Ibid.*, 1911, No. 1. p. 249.

1. The composition of the carbides separated from a series of well-annealed steels containing various percentages of vanadium, the percentage of carbon increasing with the percentage of vanadium.
2. The mechanical properties of the alloys under static and alternating stress tests.
3. The microscopical features of the alloys.

Moissan,¹ by heating together vanadic anhydride and sugar carbon in different proportions and at various temperatures in the electric furnace, prepared several samples of vanadium containing from 4.4 to 18.42 per cent. of carbon.

Moissan also found that, if the heating be prolonged, a crystalline and well-defined carbide, having the formula VC, is always obtained, which scratches quartz with ease, and is not attacked by hydrochloric or sulphuric acids.

Nicolardot² obtained the following double carbides of iron and vanadium; from steels with 0.4 per cent. carbon, and 1.5 per cent. vanadium, $\text{Fe}_3\text{C}.38(\text{V}_3\text{C}_2)$; from steels containing 0.8 per cent. carbon and 10 per cent. vanadium, $\text{Fe}_3\text{C}.60(\text{V}_4\text{C}_3)$; and from ferro-vanadium with 9 per cent. carbon and 32 per cent. vanadium, $\text{Fe}_3\text{C}.74(\text{V}_4\text{C}_3)$. He also states that the carbide of vanadium becomes richer in carbon as the vanadium content of the alloy and the temperature of preparation is raised, and points out that this increasing amount of carbon found with the vanadium, as the temperature rises, confirms the results previously obtained by Moissan.

Guillet³ has examined microscopically two series of vanadium steels as forged, and has also determined their mechanical properties.

The constitution, the effect of annealing, and the mechanical properties of the two series of vanadium steels, are described by him as follows:—

¹ *The Electric Furnace*, 1904, p. 169 *et seq.*

² *Le Vanadium*, 1905, p. 147.

³ *Journal of the Iron and Steel Institute*, 1906, No. II. p. 13, and *Étude Industrielle des Alliages Métalliques*, p. 344.

Constitution.

Groups.	Microstructure.	Carbon 0.20 per Cent.	Carbon 0.80 per Cent.
1	Pearlite	Vanadium < 0.7	Vanadium < 0.5
2	Pearlite and Carbide	0.7 < Vanadium < 3	0.5 < Vanadium < 7
3	Carbide	Vanadium > 3	Vanadium > 7

Annealing as a general rule softens vanadium steels. In the pearlitic steels which contain much carbide, the carbon is precipitated as graphite, but steels with the carbide show only a slight modification.

Mechanical Properties.—Pearlitic steels have a tensile strength and an elastic limit which rise rapidly with the percentage of vanadium; the elongation and reduction of area slowly decrease, while still preserving relatively high values; the brittleness does not increase; the hardness increases rapidly.

Pearlitic and carbide steels have a tensile strength and an elastic limit which are lower in proportion as the percentage of vanadium, and consequently the amount of the carbide, increases; the elongation and reduction of area increase, but the resistance to shock diminishes rapidly.

Steels containing the carbide have high elongations and reductions of areas, but they are very brittle.

Paul Putz¹ prepared a number of steels, with vanadium, increasing to 1.64 per cent., and carbon increasing to 2 per cent. The results of numerous tensile tests, and the examination of the sections of the steels of this series are described. The chemical formula for the vanadium carbide present in vanadium steels is stated to be V_2C_3 , or $V_{2n}C_{3n}$.

Kent Smith² describes his investigations on the properties of vanadium steels, and gives a summary of the effect of different quantities of vanadium on the static qualities of steel.

Giesen³ states that it is very difficult to judge correctly

¹ *Metallurgie*, 1906, p. 651.

² *Journal of the Society of Chemical Industry*, 1906, p. 291.

³ *Journal of the Iron and Steel Institute, Carnegie Scholarship Memoirs*, vol. 1, 1909, p. 33.

sections of vanadium steels under the microscope, since even a low vanadium content is completely dissolved by ferrite, the solution becoming saturated when the vanadium reaches 0.6 per cent. Above this quantity the vanadium unites with the pearlitic carbon to form a vanadium carbide, which comes into prominence as the vanadium in the steel increases.

Portevin,¹ working on steels containing 0.2 per cent. carbon, and from 0.6 to 0.7 per cent. vanadium, and also 0.8 per cent. carbon, and from 0.25 to 1.0 per cent. vanadium, arranges the vanadium steels in three groups:—

- | | |
|-----------|--------------------------------------|
| 1st Group | Pearlitic steels. |
| 2nd „ | Pearlitic and double carbide steels. |
| 3rd „ | Double carbide steels. |

Hatfield,² from his experiments on the influence of vanadium upon the physical properties of cast irons, comes to the following conclusions, amongst others—that silicon is partially prevented from crystallising with the carbide by vanadium, and that by the presence of much of the vanadium in the carbide, the carbide is rendered more stable.

METHOD OF MANUFACTURE OF THE AUTHORS' STEELS.

The alloys were made by the coke crucible process in Sheffield white clay pots from Swedish bar iron, American washed iron, and 38 per cent. ferro-vanadium; 0.05 per cent. of metallic aluminium was added to each a few minutes before teeming. The ingots, $2\frac{3}{4}$ inches square, and each weighing 40 lbs., were cogged and hammered into bars $1\frac{1}{8}$ inch round. The bars were heated to about 950° C. for six hours, and were allowed to cool during an additional twelve hours.

CHEMICAL COMPOSITIONS OF AUTHORS' SERIES.

The analyses of the steels were made on the last turnings from the carbide bars. The results are given in Table I.

¹ *Journal of the Iron and Steel Institute, Carnegie Scholarship Memoirs*, vol. i. p. 333.

² *Journal of the Iron and Steel Institute*, 1911, No. I. p. 318.

TABLE I.

Number of Steel.	Carbon per cent.	Vanadium per cent.	Silicon per cent.	Phosphorus per cent.	Manganese per cent.	Sulphur per cent.	Aluminium per cent.
1315	0.60	0.71	0.05	0.01	0.06	0.04 or under	Under 0.01
1316	0.63	2.32	0.09	0.01	0.07		
1309	0.93	5.84	0.21	0.02	0.11		
1310	1.07	10.30	0.32	0.03	0.12		
1312	1.10	13.45	0.47	0.03	0.12		

DETERMINATION OF THE CARBIDES.

The method and treatment used for separating the carbides was the same as described in the authors' last paper already referred to,¹ but with this modification, that the residues were dried at 100° C. in a current of hydrogen, the tube being pumped out from time to time. The steels dissolved quite readily, and with each member of the series vanadium was found in the hydrochloric acid solutions; but in most cases it was quite unnecessary to test for vanadium, as the electrolyte was distinctly blue to dark blue in colour.

The carbides obtained from Nos. 1315 and 1316, containing 0.71 and 2.32 per cent. of vanadium, were dark grey; and from Nos. 1309, 1310, and 1312, containing 5.84, 10.30, and 13.45 per cent. of vanadium, slate grey in colour.

The analyses of the carbides were carried out as follows: The porcelain boat containing the dried carbide was weighed. About one-half of the carbide was carefully removed and put on one side for the determination of iron and vanadium. The boat was again weighed, the carbide well mixed with pure manganese dioxide, and the carbon estimated by direct combustion. The remaining portion of the carbide was intimately mixed with sodium carbonate and a small quantity of sodium peroxide in a platinum basin, and heated in a muffle furnace. When cold the mass was repeatedly boiled with water and

¹ *Journal of the Iron and Steel Institute*, 1911, No. 1. p. 249.

TABLE II.

No. of Steel.	Carbon per Cent.	Vanadium per Cent.	Ampères.	Volts at Terminals.	Time in Acid.	(Grammes Dissolved.	Weight of Dry Residue.	Percentage of Total Carbon obtained with Carbide Residue.	Analysis of Carbide.	Corresponding to the Formula.	Carbon per Cent.	Iron per Cent.	Vanadium per Cent.	Theory.
1315	0.60	0.71	0.5	0.6 to 1.5	12 hours	8.920	0.6753	95.77	7.61	83.71	8.68			
"	"	"	"	"	"	8.926	0.6847	96.98	7.66	83.69	8.65			
"	"	"	"	"	11 hours	8.250	0.6154	92.71	7.49	83.27	9.24			
1316	0.63	2.32	"	0.7 to 1.2	"	8.054	0.4346	88.10	10.66	51.60	34.74			
"	"	"	"	"	"	8.053	0.4148	82.80	10.44	54.71	34.85			
"	"	"	0.55	"	10 hours	7.630	0.4180	91.20	10.63	53.30	36.07			
1309	0.93	5.84	0.5	0.8 to 1.3	12 hours	8.625	0.5066	99.15	15.94	0.54	83.52			
"	"	"	"	"	"	8.612	0.4973	98.19	15.94	0.47	83.59			
"	"	"	"	"	"	8.313	0.4890	97.63	16.05	0.83	83.12			
1310	1.07	10.30	"	0.8 to 1.4	"	8.168	0.5952	96.76	15.03	1.04	83.93			
"	"	"	"	"	"	8.160	0.5732	95.22	15.00	0.63	84.37			
1312	1.10	13.45	"	0.8 to 1.6	"	8.303	0.6757	99.78	14.12	0.82	85.06			
"	"	"	"	"	"	8.571	0.7207	99.06	13.76	1.27	84.97			
											15.00			85.00

1 These carbide residues were boiled for one hour with dilute sulphuric acid (1 of acid to 10 of water), then washed, treated, and dried in the usual way.

filtered. The vanadium in the filtrate was estimated by reducing with sulphurous acid and titrating with a standard solution of potassium permanganate. The residue on the filter paper was dissolved in hydrochloric acid and made up to a known volume. The iron was then estimated by the usual volumetric process, using a standard solution of potassium dichromate for the titration. The very small quantity of vanadium found in the iron solution was determined by the hydrogen peroxide colour test. The results are given in Table II.

A consideration of the results in the foregoing table indicates that in most cases practically the total amount of carbon in the steel is obtained as carbide. The slightly lower results

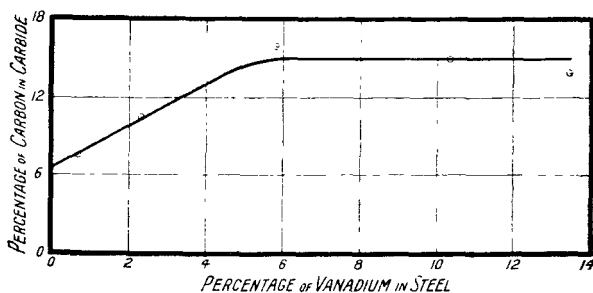


FIG. 1.

are not due to any appreciable decomposition of the carbide during the electrolytic run, but are accounted for by a slight roughness of the bars which prevented the last traces of carbide being obtained.

The results given in Table II. also show that vanadium replaces iron in the carbide, even when the steel contains only such a small quantity as 0.71 per cent. of vanadium, with the formation of a mechanical mixture of the carbides of iron and vanadium corresponding to the formula $11\text{Fe}_3\text{C} + \text{V}_4\text{C}_3$.

As the vanadium in the steel increases, more vanadium is found in the carbide, and with the next member of the series, containing 2.32 per cent. of vanadium, the carbide is represented by the formula $2\text{Fe}_3\text{C} + \text{V}_4\text{C}_3$.

Coming to the remaining three steels of the series, with

5.84, 10.30, and 13.45 per cent. of vanadium, in each case practically the whole of the iron has been replaced by vanadium, and most probably a definite carbide of vanadium is obtained, corresponding to the formula V_4C_3 .¹

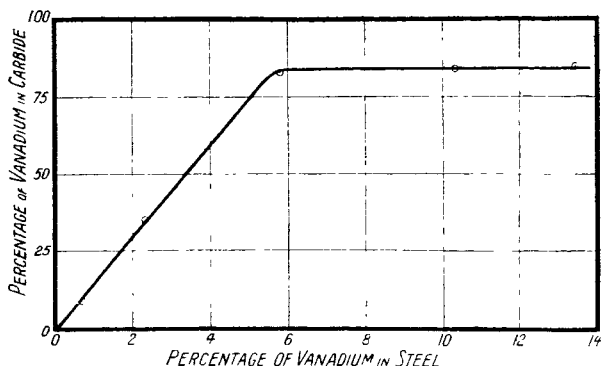


FIG. 2.

These results are shown more clearly in Figs. 1 and 2. It will also be noticed (Table II.) that it is possible to reduce still further this small quantity of iron found with the vanadium by digesting the carbide residues with hot dilute sulphuric acid.

TURNING CHARACTERISTICS OF THE ALLOYS.

The report of Mr. J. Harrison, Laboratory Engineer in the Metallurgical Department of Sheffield University, on the behaviour of the bars in the lathe is embodied in the following table, the word tough having reference to the capability of the material to curl off in spirals during the turning operations:—

Steel No A.	Carbon per Cent	Vanadium per Cent.	Turning Report
1315	0.60	0.71	Tough
1316	0.63	2.32	
1309	0.93	5.84	Tough and slightly hard
1310	1.07	10.30	
1312	1.10	13.45	Tough and hard

¹ It is theoretically possible that this may be a mixture of vanadium carbides.

MECHANICAL PROPERTIES.

The static results are embodied in the following table, the test-pieces being 2 inches parallel and 0·564 inch diameter :—

Table of Tensile Tests.

Steel No. A.	Yield Point, Tons per Sq. Inch.	Max. Stress, Tons per Sq. Inch.	Elongation per Cent.	Reduction of Area per Cent.
1315	12·0	35·9	22·0	41·4
1316	14·0	35·0	24·5	52·0
1309	17·0	33·4	25·0	53·2
1310	15·0	33·7	23·0	31·5
1312	18·0	37·0	10·0	9·7

Since 1309 contains 0·93 per cent. of carbon, its test result is remarkable.

ALTERNATING STRESS TESTS.

The dynamic tests obtained under standard conditions on the Arnold machine are tabulated as follows :—

Table of Alternating Tests.

Steel No. A.	Alternations Endured		
	1st Test.	2nd Test	Mean
1315	126	112	119
1316	162	220	191
1309	144	126	135
1310	94	144	119
1312	8	22	15

The poor dynamic properties of the series exemplify the evil influence of drastic annealing on vanadium steels.

MICROGRAPHIC ANALYSIS.

The microscopical examination of the steels leads the authors to announce provisionally the discovery of two new

constituents—1. Vanadium pearlite; 2. Vanadium cementite, V_4C_3 .

1. *Vanadium Pearlite.*

This constituent seems incapable of segregating into the laminated variety, and presents itself only in the troostitic and sorbitic forms. Its saturation point seems considerably higher than that of iron pearlite, but this point requires further research.

2. *Vanadium Cementite.*

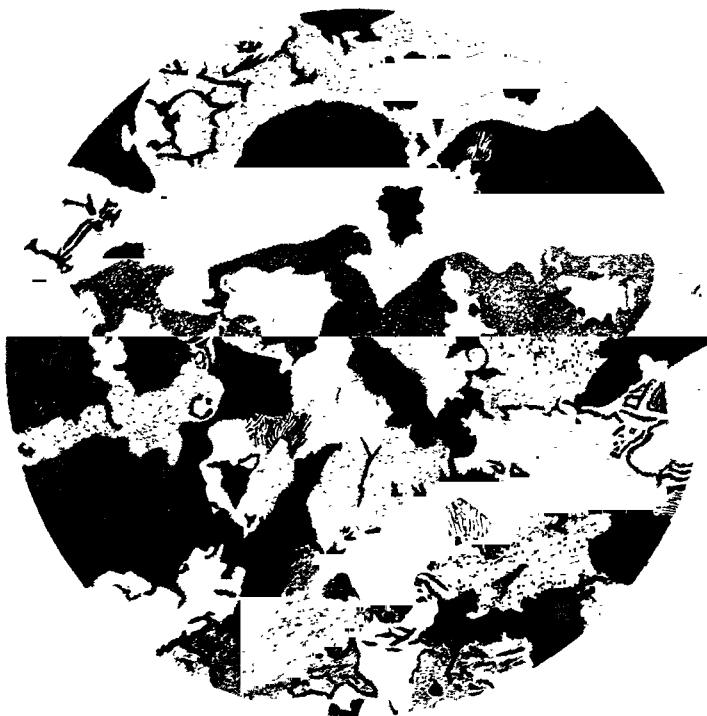
This constituent (a decomposition product of vanadium pearlite) is not nearly so mobile as Fe_3C , and consequently segregates into relatively minute irregular masses very much smaller than massive iron cementite.

The micrographic analysis has proved—almost beyond doubt—that there is no double carbide of iron and vanadium. since when Fe_3C and V_4C_3 are together in a well-annealed steel the former has segregated as usual, whilst the latter has remained distributed in its pearlite in the troostitic or sorbitic form.

Micrograph No. 1.—In this structure was found (*a*) a pale ground-mass of slightly vanadiferous ferrite; (*b*) a few areas of laminated iron pearlite; (*c*) the Fe_3C of decomposed laminated iron pearlite in the form of cell walls and irregular masses; (*d*) dark etching troostitic vanadium pearlite; (*e*) less-dark etching areas of sorbitic vanadium pearlite. This section contains 0·6 per cent. carbon and 0·71 per cent. vanadium (Plate XXII.).

Micrograph No. 2.—This steel presents a very confused structure in which vanadiferous ferrite and vanadium pearlite in both the troostitic and sorbitic forms have segregated very imperfectly in spite of the twelve hours cooling. The only well-defined constituent is the iron cementite which has readily segregated in meshes and masses, but is distinctly less in quantity than that in Micrograph No. 1. The steel represented contains 0·63 per cent. carbon and 2·32 per cent. vanadium (Plate XXIII.).

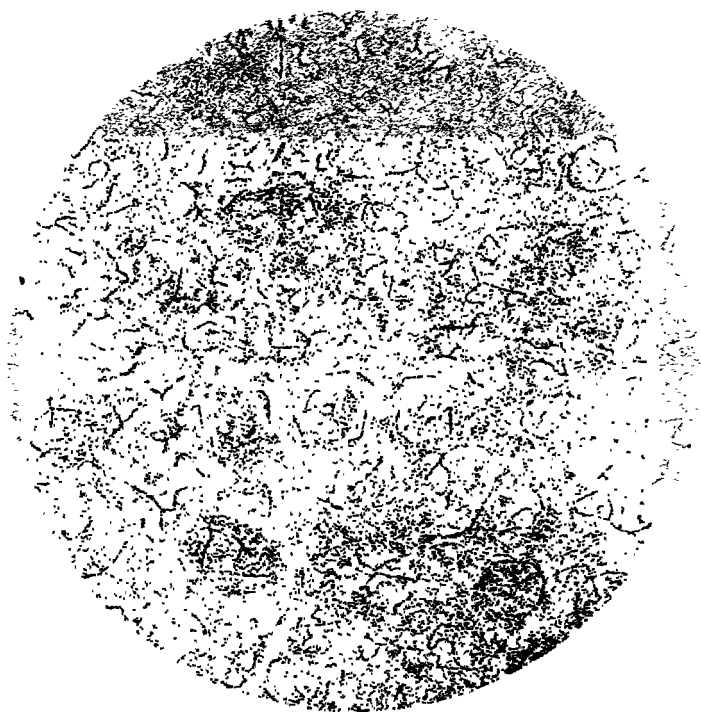
Micrograph No. 3.—This section consists largely of sorbitic vanadium pearlite, overlaid, however, by irregular meshes.



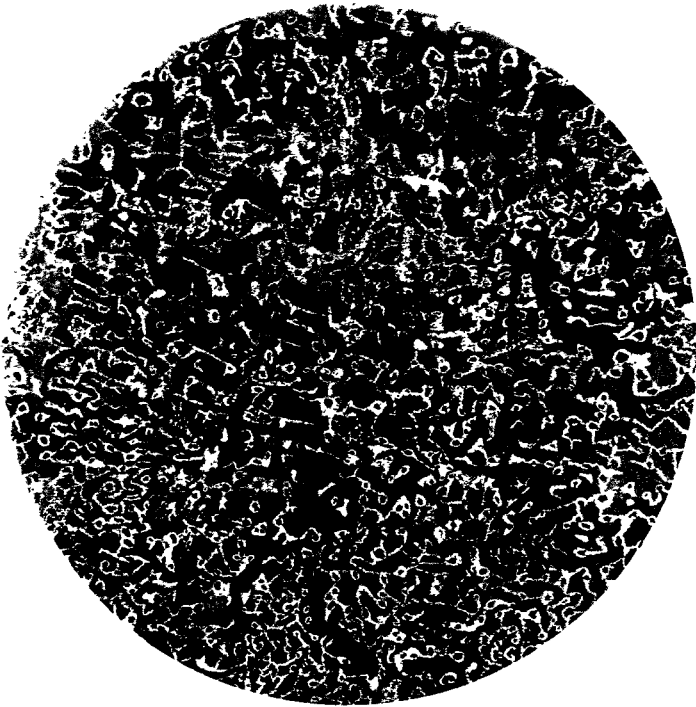
MICROGRAPH No. 1.
Carbon, 0·60 per Cent. ; Vanadium, 0·71 per Cent.
Magnified 450 diameters.



MICROGRAPH No. 2.
Carbon, 0.63 per Cent. ; Vanadium, 2.32 per Cent.
Magnified 450 diameters.



MICROGRAPH No. 3.
Carbon, 0.93 per Cent. , Vanadium, 5.84 per Cent.
Magnified 450 diameters.



MICROGRAPH No. 4.
Carbon, 1.10 per Cent ; Vanadium, 13.45 per Cent.
Magnified 450 diameters.

apparently of vanadiferous ferrite. In other words, the steel is not saturated. It contains 0.93 per cent. carbon, and 5.84 per cent. vanadium (Plate XXIV.).

Micrograph No. 4.—This contains 1.10 per cent. carbon, and 13.45 per cent. vanadium. It is almost identical in structure with steel No. 1310, which contains 1.07 per cent. carbon and 10.30 per cent. vanadium. The ground-mass is vanadiferous ferrite, over which are scattered small segregated irregular masses of vanadium cementite, V_4C_3 . Each particle is environed by a somewhat dark border of probably sorbitic vanadium pearlite, and small patches and streaks of this constituent are also scattered over the field. The mobility or segregative capacity of V_4C_3 obviously increases with the percentage of vanadium present in the ferrite (Plate XXV.).

RECALESCENCE OBSERVATIONS.

Steel No. 1316.—Carbon, 0.63 per cent.; Vanadium, 2.32 per cent.

Cooled from 1020°C ., this steel did not present the point Ar3. Ar2 appeared at 791°C . and Ar1 at 720°C . This latter point was very small for a 0.63 per cent. carbon steel.

Steel No. 1310.—Carbon, 1.07 per cent.; Vanadium, 10.3 per cent.

Cooled from 1210°C ., this steel failed to present the point Ar3. Ar2 presented the top peak at 830°C . and the lower peak at 816°C . Ar1 was quite absent. On heating, the maximum absorption at Ac2 was at 826°C . Ac1 was absent.

QUENCHING EXPERIMENTS.

Samples of steel No. 1310, carbon 1.07 per cent., vanadium 10.3 per cent., were rapidly quenched from the following temperatures: 850°C ., 1000°C ., and 1050°C . All after quenching were quite soft to the file. The authors provisionally draw the following conclusions:—

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- (a) That the point Ar₁, marking the formation of vanadium pearlite from vanadium hardenite, must be between 1200° C. and 1400° C. (the latter being about the solidification point of the steel). When quenched in water from about 1300° C., steel No. 1310 was quite hard, stripping a new file.
- (b) That although the steel be quenched in the beta range of temperature, it is still quite soft.
- (c) That the above conclusions, when fully confirmed, will form direct proof of the correctness of the views so long held by Professor Le Chatelier, Sir Robert Hadfield, Dr. McWilliam, and the authors, that the hardening of steel is brought about by carbon in some form irrespective of the range of temperature.

Further experiments have resulted in the discovery of vanadium hardenite, which is formed near 1400° C. It resembles iron hardenite but seems as hard as topaz.

The authors have to thank Mr. F. C. Thompson, B.Met., Demonstrator of Metallurgy in Sheffield University, for his services in carrying out the foregoing experiments.

In conclusion, the authors have to tender their thanks to Mr. F. K. Knowles, B.Met., Senior Lecturer in Metallurgy at the University of Sheffield, for much valuable help in making the steels and mechanical tests; also to Mr. Duncan Maxfield, Associate in Metallurgy of Sheffield University, for the patience and accuracy of his work connected with the chemical branch of the research. Finally, the authors have to thank Mr. E. Colver-Glauert, Research Assistant in the University of Sheffield, for his exquisite micrometric reproductions of the four typical micrographs illustrating this paper.¹

The authors hope at no distant date to report to the Institute on the chemical and mechanical relations of iron carbon and nickel. In view of a suggestion made at the last

¹ The term "sorbite," as used in this paper, has reference to pearlite, in which the carbide, although in a fine state of division, is nevertheless within the range of microscopic vision.

The term "troostite" has reference to pearlite, in which the carbide is in a state of division so fine as to be beyond the range of microscopic vision.

May meeting of the Institute by their friend Dr. Stead, the authors wish to state that the absorption and recalescence curves of the steels dealt with in all their carbide researches will be included in a special paper as soon as possible after the unique recalescence laboratory now being fitted up for the Sheffield University by the Cambridge Scientific Instrument Company is available for work.

DISCUSSION.

Mr. E. H. SANITER, Bessemer Medallist, said he had read Professors Arnold and Read's paper with great interest, and it seemed to him that an exceeding interesting point had been brought out.

In the same connection it was interesting to recall the authors' paper on chromium carbides, and also Mr. Moore's¹ on the A_2 point in chromium steels. The authors' previous paper went to prove that the chromium carbides existed as double carbides, and now the present paper pointed out that vanadium carbide was only a mixture with iron carbide.

On the last page of the paper the authors remarked that the recalescence point at 720° seemed only a small one for a 0.63 per cent. carbon steel. That seemed only natural, however, as only the carbide of iron would react, the vanadium carbide being inert at the temperatures used, and to obtain the benefit of the vanadium in such a steel it would be necessary to heat up to the solution point of the vanadium carbide.

In that connection it would be interesting to know if, in a chromium vanadium steel, the vanadium carbide formed a double carbide or not. Mr. Moore in his paper proved that the Ar_{1-2} point moved up to 820° C., while the A_2 point remained stationary at 760° C. It seemed to him that the authors had discovered a similar phenomenon in connection with vanadium carbide at about 1300° . The paper was a very interesting one, and might lead to very important developments.

Dr. F. ROGERS (Sheffield) said there were some very important matters mentioned in the Appendix to the paper, but until all the data on which the authors founded some of those conclusions were available, it would be very difficult to discuss them. In the first place, he would like to know what meaning the authors attached to Ar_2 and Ac_2 in that instance, because he (Dr. Rogers) also remembered Mr. Moore's paper, which showed that the relative positions of the recalescence points were altered in certain chromium steels. It was usual to call the magnetic change point Ar_2 and Ac_2 . Was that the case with the authors' experiments? Again, what was really

¹ "The A_2 Point in Chromium Steels," *Journal of the Iron and Steel Institute*, 1910, No. 1. p. 268.

the β -range in that case? Professor Arnold used the term β -range, and he was the only observer who did, and it was necessary to know what he meant in that instance. It seemed to him (Dr. Rogers) that the authors really opened up again the allotropic *versus* carbon controversy. The real point in that controversy was that the allotropists' explanation of the hardening of carbon steels was not only that iron carbide was retained in the form of solution, but also that β -iron was hard. That hard β -iron theory was really only an encumbrance, and he did not think anybody had attached much importance to it for some years as an explanation of the hardening of carbon steels. It was necessary first to perfect the theory of carbon steel before a reliable theory of alloy steels could be elaborated. In passing from carbon steels to alloy steels, it appeared to him that the very strongest support of the allotropic theory was found in the study of the gradual and continuous modification of the properties of the steels as the amount of alloy was progressively increased. That was shown very clearly in some of the authors' curves, which indicated the gradual elimination of iron carbide. The mere fact brought out by the authors that there was hardening by retaining vanadium carbide in the form of solution was simply an intrinsic property of vanadium, and did not upset the allotropic theory at all. On account of that fact new critical points occurred in the vanadium steels, and those must have new names. It was rather confusing to give them the names A_1 and A_2 , and so on; they should have names of their own which would suggest that another phenomenon was occurring at those critical points, and then it could be ascertained which, if any, might properly be designated the β -range. He expected that the so-called β -range in the paper would have to be revised.

Dr. WALTER ROSENHAIN (Teddington), regarded Professor Arnold's papers with great interest, but, as might be expected, that interest was accompanied by a good deal of disagreement. He thought that those studies of the ternary alloys were of the highest importance, and he hoped that what he had to say in criticism would not be regarded as depreciating in any way the value of that work; he wished to express his admiration for certain parts of the work, although he disagreed strongly with other parts. First, as regards cementite and hardenite, he would ask, What was hardenite? That was a term he did not know, in the sense that he had never seen any satisfactory definition of it. When Professor Arnold came forward with an equilibrium diagram of the iron-carbon system, and a definition of hardenite consistent with such a diagram and with the known laws of heterogeneous equilibria, metallurgists might be expected to take Professor Arnold's terms seriously. Dr. Rosenhain himself could not accept a term until it was defined in that way, although, on the other hand, he did not wish to suggest that Professor Arnold should be coerced into using terms of which he disapproved; but he could not see why, if Professor Arnold agreed with the idea that steel above the recalescence points was in the state of a solid solu-

tion, he should apply a term to it different from that which was almost universally accepted. Now Professor Arnold went further, and introduced the term "vanadium hardenite," making confusion worse confounded. He thought that a strong protest was needed against the introduction of such terms as "vanadium hardenite" and "vanadium cementite" without a perfectly sound and satisfactory definition. He quite realised that these two constituents required a name, but surely cementite and pearlite were terms so well known and well defined that he did not think that it tended towards clearness if a new constituent of a totally different constitution (V_4C_3) were given a corresponding name. He thought that "vanadium carbide" would meet the case perfectly well, or some other purely descriptive name. When it came to "vanadium pearlite," he thought matters were rather worse, because that name suggested that the new constituent was in character and mode of origin similar to pearlite; yet on Professor Arnold's own description the similarity was to sorbite rather than pearlite. Before the term "vanadium pearlite" could be accepted, it would have to be shown that the constituent was the result of the decomposition of a solid solution on analogous lines to that by which pearlite was formed. He would like to ask Professor Arnold whether, so far as his results had gone, he had any evidence to show that in the case of his "vanadium pearlite," there were any reactions equivalent to those which occurred when iron carbide was deposited from solution at the recalescence point? When the freezing point of vanadium steel and the temperature at which Professor Arnold suggested that "vanadium pearlite" was formed were known, and the reactions accompanying that formation had been studied, the resulting substance might be shown to be analogous to pearlite; but apparently at the present stage Professor Arnold was not in a position to say, so far as his published data were concerned, whether that vanadium constituent was really separated from a solid solution at all, or whether it was deposited direct from fusion.

He was much interested in one statement, namely, that the conclusions, "when fully confirmed, will form direct proof of the correctness of the views, so long held by Mr. Le Chatelier, Sir Robert Hadfield, Dr. McWilliam, and the authors, that the hardening of steel is brought about by carbon in some form irrespective of the range of temperature." It came as a pleasant surprise to him to find that there was a theory upon which Professor Arnold and Mr. Le Chatelier had agreed for any considerable time past. He felt it a little difficult to believe in such a theory, although it was sufficiently vague to be subscribed to by most metallurgists, since no man who had studied the metallography of steel would dispute the fact that carbon had something to do with hardening. Whether β -iron played a part in hardening or not was open to discussion, and if Professor Arnold's experiments proved that it did not, he would be very well pleased to have the matter settled. There were, however, difficulties in the way of accepting evidence obtained

from a steel containing 10 per cent. of vanadium as bearing upon the functions of β -iron in carbon steels. Thus he would like to associate himself with Dr. Rogers, and ask Professor Arnold what justification he had for calling those recalescence points in vanadium steel Ar_2 ? It was, of course, quite true that they occurred somewhere near the temperature characteristic of Ar_2 in carbon steels; but, on the other hand, there was so much carbon present in those alloy steels that they would lie outside the range in which Ar_2 is found as an independent point in carbon steels at all. Secondly, he (Dr. Rosenhain) did not think that the argument derived from the behaviour of vanadium steels quenched above or below that recalescence point bore directly on the question of the part played by β -iron in the hardening of carbon steels.

He hoped that the vigour with which he had controverted Professor Arnold's views would be regarded as evidence of the interest that he had taken in the paper, and that Professor Arnold would appreciate it in that sense.

Dr. J. E. STEAD, F.R.S., Vice-President, congratulated the authors upon the immense amount of very useful work they had done. The time and pains required in separating, analysing, and determining the mechanical properties of the alloys must have been enormous. The question as to whether the carbides which separated on annealing simply passed, as such, into solid solution, was one which should have further consideration. Apparently the authors had not attempted to separate the carbides from the hardened steels. He would like to know if the authors had determined the mechanical and electrical properties of those alloys, as that information was necessary before a decision could be arrived at as to the significance of the critical points. It was possible that in alloys of that kind they might represent something entirely different from the corresponding arrests which occurred in pure carbon steels. He thought, perhaps, it was somewhat inadvisable to call the hard substance produced by quenching alloy steels by the term hardenite, even if qualified by a prefix, such as vanadium, &c. Hardenite had been defined specifically as approximating to the composition $Fe_{24}C$, and it seemed to him inadvisable to apply the term to a substance of entirely different composition.

Mr. C. A. EDWARDS (Middlesbrough) said there had been so much destructive criticism, that he would deal only with what he regarded as the points of real importance brought out in that paper. The discovery that the addition of vanadium to iron-carbon alloys raised the temperature at which the Ar_2 critical points occurred was very interesting, and so far as he (Mr. Edwards) was aware, it was the first known case of its kind. There seemed to be no possible reason for doubting that the authors were correct in their interpretation of what they described as the Ar_2 point, since the double carbide of iron and vanadium did not go into solution unless the metal were heated to about $1200^\circ C.$, and therefore could not have any influence upon the

temperature at which the Ar_3 point took place. In view of the fact that vanadium was now widely used in "high speed steels," he (Mr. Edwards) would like to ask the authors what they considered to be the theoretical effect of that element upon the thermal changes of such steels?

Professor T. TURNER (Birmingham) referred to the fact that the authors apparently regarded iron carbide as existing at high temperatures. That was a view he had always taken, and was still inclined to take; but there was one important experiment made some years ago by one of Professor Arnold's old students who was working at the time in his (Professor Turner's) laboratory,¹ in which he took a specimen of hard steel and placed soft steel on either side. He then placed it in a tube, and exhausted the tube. He then heated the specimens, and found that the carbon migrated from the hard steel to the soft steel outside, as was to be anticipated; but he weighed the samples and found that the amount of carbon gained by the pieces outside was exactly the same as the weight lost by the piece inside, so that there was an actual gain of carbon and not of iron and carbon. If the iron carbide were in entropy at that temperature it ought to have passed out of the high-carbon steel into the low-carbon steel, with a difference in weight to that due to the carbon alone. He had intended to give notice of that question, and if Professor Arnold was not prepared to answer it now, perhaps he would answer it later on. It seemed, at all events, at first sight, to prove that carbon existed in the free form at that high temperature, and yet that was not what he (Professor Turner) was inclined to believe.

Mr. W. H. HATFIELD (Sheffield) said that, after all, new facts were what the Institute really desired with regard to the chemical relations of iron, vanadium, and carbon. Like other papers in the same series which Professors Arnold and Read had published, the new paper contained much new data, which was likely to prove of value. He would like to ask the authors one question, and that was as to the existence of a double carbide of iron and vanadium. Last year he (Mr. Hatfield) read a paper on the influence of vanadium upon the stability of iron carbide, and Professor Arnold, in the present paper, now stated that "the micrographic analysis has proved—almost beyond doubt—that there is no double carbide of iron and vanadium. . . ." If Professor Arnold would refer to his (the speaker's) micrographs, published last year, he would find that the carbide itself, with increase in vanadium content, became more stable with increased temperatures, and was not as liable to dissociate. That rather pointed to a double carbide existing in the particular specimen, and the particular conditions under which he examined them.

¹ G. P. Royston, *Journal of the Iron and Steel Institute*, 1897, No. I. p. 172.

CORRESPONDENCE.

Dr. F. ROGERS (Sheffield) wrote that upon studying the authors' data from the point of view of solution theory two or three very important conclusions seemed to be indicated to which attention had not been directed in the paper. It was an almost inevitable consequence of adopting the solution theory standpoint, that he also adopted the allotropic view of the constitution of steel, but he would emphasize the reservation which he had made in the discussion, namely, that he considered as superfluous the conception of the hardening of carbon steels as being partly dependent upon any hardness of β -iron. He would endeavour in the following remarks to avoid controversial nomenclature so far as was consistent with lucidity. The principal conclusions he would draw were:—(1) Vanadium and iron formed a series of solid solutions with one another which was probably unlimited. (2) Vanadium carbide (V_4C_3) was probably soluble in molten iron, and quite, or nearly, insoluble in solid iron. There was no evidence to show whether some degree of difference was caused if the iron carried some vanadium in solution. (3) Carbon had a stronger affinity for vanadium than for iron, since, with increasing vanadium, vanadium carbide tended to preponderate and iron carbide to disappear, and with 0.93 per cent. carbon and 5.84 per cent. vanadium (steel No. 1309) there was no iron carbide at all. Since those numbers were almost proportional to the quantities demanded by the formula V_4C_3 , it appeared probable, and it would be a fundamental point requiring confirmation, that in a steel with lower contents of carbon and vanadium, but bearing the same ratio, about 1:6, the carbon would all be combined with vanadium and none of it combined with iron. Although those conclusions were partly based upon the critical point observations recorded by the authors, it was necessary to have stated those conclusions first in order to make the following remarks about the critical points more clear. (4) The exact effect of vanadium in solid solution in iron upon the critical points would be difficult to determine. If A_1 was affected at all, it was raised slightly by the presence of vanadium. A_2 was probably raised slightly, and A_3 lowered slightly. (5) The effects on the points A_1 , A_2 , A_3 , due to the presence of vanadium carbide, were exactly and only the indirect action of gradual deprival of iron carbide of its carbon in favour of the formation of vanadium carbide; that was, A_1 and A_3 corresponded to A_1 and A_3 of a carbon steel which contained the same amount of iron carbide, and A_2 was also otherwise unaffected. (6) The critical temperatures were thus dependent on conclusions (4) and (5) jointly, and it was seen that that led to some important positions. Of those, one of the most important was that in steels in which the ratio of vanadium to carbon content exceeded about 6:1, the critical points A_1 , A_2 , A_3 would be much the same as in pure iron, namely, A_1 absent, A_2 well marked, A_3 rudimentary. Those points would be shifted in

accordance with the amount of excess vanadium in solid solution in iron, as stated under conclusion 4.

Those remarks implied that he (Dr. Rogers) did not consider that in the vanadium steels there was any evidence that A_1 or A_3 was raised up to 1200° to 1400° C. It was yet an open question whether the phenomena occurring at the high temperatures mentioned were related to the completion of solidification or occurred in the solid state; but the conclusion embodied under (2) seemed the most probable explanation. Thus, on chilling from a temperature slightly above a certain line, probably representing a constant temperature of, say, 1300° C., vanadium carbide was retained in the form of solution in iron, and the steel was hard. Apart from the question whether that temperature was below the temperature of complete solidification or not, that phenomenon was thus closely analogous to the changes occurring at the A_1 and A_3 points in carbon steels, but was distinctly not the same phenomenon shifted up to a higher temperature by the presence of vanadium. If the hardening was brought about entirely in the solid state, clearly there must be a new critical point or points at that high temperature, which would be neither A_1 nor A_3 , and admittedly was not A_2 . But it was more probable that that hardening temperature was the solidus, in which event it would not require a special name.

It would be seen that the foregoing explanations would justify the criticism which he (Dr. Rogers) made in the discussion of the authors' use of the term " β -range." Whilst the comparison with the case of chromium steels could not be carried far, it was only used to show that since the relative positions of critical points might change, the significance of a range between two given critical points being subject to special interpretations, according to the case. Referring to the statement that steel did not harden when quenched from 850° C. because it contained no iron carbide, its behaviour was that of iron with a little vanadium (about 4.5 per cent.) dissolved in it, and holding also some small grains of vanadium carbide, but not in solution, at the quenching temperature.

Professors ARNOLD and READ, in replying to the discussion and correspondence, wrote that they quite agreed with Mr. Saniter that the upward movement of the point Ar_1 , noted by Mr. Moore as due to chromium, was of a similar nature to the enormously greater raising of the point observed by themselves in the case of vanadium.

In reply to Mr. Rogers, the authors were under the impression that the term "range" was well understood. For instance, in a 0.2 per cent. carbon steel the Ar_1 , Ar_2 , and Ar_3 transformations had a certain amplitude, and the temperatures included between the end of one amplitude and the beginning of the next was obviously a "range," and theoretically one got three ranges, viz. the α -range below the beginning of the amplitude of Ac_2 , the β -range from the end of the amplitude of Ac_2 to the beginning of the amplitude of Ac_3 , and the γ -range

above the end of the amplitude of Ac_3 . With reference to the nomenclature of the three new constituents discovered by the authors, with all due deference to Drs. Rogers, Rosenhain, and Stead, the authors humbly claimed the right to christen their own children and proposed to exercise it. Of course those gentlemen, after their wont, could alter the authors' terms for their own purposes and call the new constituents by any name they pleased. Dr. Stead had kindly mapped out further work for the authors, and no doubt such work was desirable, but the authors would respectfully suggest to Dr. Stead that a little practical help was worth a world of advice. Dr. Rosenhain and his somewhat slavish adherence to equilibrium curves did not appeal to the authors, since as practical men their faith in such curves fell far short of that of Dr. Rosenhain. Dr. Rogers did not consider there was any evidence that the point Ar_1 was raised much. Then where was it? It certainly did not present itself in a 1 per cent. steel high in vanadium between 550° and 1250° C. Mr. Edwards was much nearer the mark when he recognised that the new facts pointed the way to a correct theory, explaining the extraordinary properties of high-speed steels. With reference to Mr. Royston's results, Professor Turner was not inclined blindly to accept them, and in that respect his views were coincident with those of the authors, since they had never been confirmed.

Finally, the authors wished to reiterate for the benefit of Dr. Rosenhain that the coincidence of their views with those of Professor Le Chatelier as to the cause of the hardening of steel being due to carbon and α -iron were widely known.

NOTES ON THE SOLUBILITY OF CEMENTITE IN HARDENITE.

BY JOHN OLIVER ARNOLD, D.MET.,

AND

LESLIE AITCHISON, M.MET.

(SHEFFIELD TOWN TRUST RESEARCH FELLOW, AND DEMONSTRATOR OF
METALLURGICAL CHEMISTRY IN THE UNIVERSITY OF SHEFFIELD).

FOR the purposes of this research the following steels were prepared by the crucible process:—

STEEL No. 1291.

This was cast into an ingot $1\frac{3}{4}$ inch square and hammered down to $\frac{3}{4}$ inch round.

It was slightly supersaturated, containing—

	Per Cent.
Carbon	1.050
Silicon	0.046
Manganese	0.100
Sulphur	0.023
Phosphorus	0.012

STEEL No. 1290.

This was experimented upon as cast. It was a well supersaturated steel containing—

	Per Cent.
Carbon	1.460
Silicon	0.046
Manganese	0.100
Sulphur	0.025
Phosphorus	0.012

METHOD OF HEATING AND QUENCHING.

Fig. 1 shows full size duplicate sections prepared for quenching. MM are the two microsections attached by

narrow necks to the main body of the steel which contains a

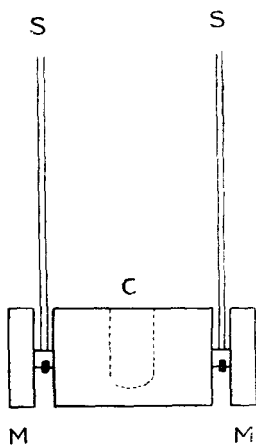


FIG. 1.—Full size.

recess C for the thermocouple. The whole is loosely suspended in the bath by the wires, SS. Fig. 2 shows the

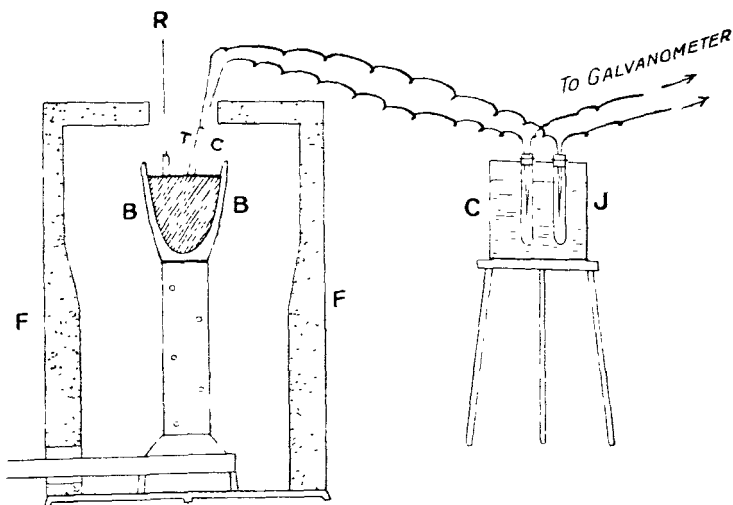


FIG. 2.—Sectional Sketch of Heating Apparatus.

general heating arrangements. FF is a gas-furnace heating the salt-bath crucible, BB. This contains a mixture of

barium and calcium chlorides, together with a little potassium cyanide. The rod, R, is attached to the suspension wires and enables the pieces to be moved about to ensure equal bath temperatures throughout. The narrow quartz tube, TC, contains the thermocouple. The leads pass to the cold junction, CJ, and thence to a Le Chatelier pyrometer reading to 1° C. The quenchings, made in an ample tank of cold water and brine, did not occupy more than one second.

ABSORPTION CURVES.

Steel No. 1291 presented the maximum of the combined point Ac 1, 2, 3 at 727° C. Steel No. 1290 presented the point at 728° C.

PREPARATION OF MICROSECTIONS.

The pair of sections were broken off through the attaching necks, and $\frac{1}{32}$ of an inch was ground (with every precaution) from the faces of the sections. These were polished on emery-paper and finally on a rapidly revolving block charged with water and fine alumina. They were etched either with a 5 per cent. alcoholic solution of picric acid, or with 1 per cent. nitric acid solution as most convenient, and were then dried, examined, and photographed.

REMARKABLE QUENCHING PHENOMENON.

Rapid as was the quenching, it was found, nevertheless, that although the circumferences of the sections were probably trapped in the condition in which they existed at the quenching temperatures, the centres had been let down more or less completely to troostitic material by heat conducted from the mass of the steel through the necks to the microsections.

THE 1.05 PER CENT. CARBON STEEL NO. 1271 (FORGED).

The normal section of this steel consisted as usual of pearlite dotted over with irregular patches of cementite.

When quenched from 741°C . the cementite does not seem to have dissolved in the hardenite to any great extent. Plate XXVI. shows the section well etched with nitric acid. The white cementite patches are clearly visible, whilst the dark etching hardenite shows an indefinite granularity.

Quenched from 750°C ., etched with picric acid, the mass is nearly all structureless hardenite, only a few pieces of dark cementite (due to reflection) remaining undissolved. (See Plate XXVII.)

Quenched from 755°C ., etched with nitric acid, the whole of the cementite appears to have passed into solution. The whole mass is a dark etching substance consisting of austenitic hardenite presenting an indefinite granularity. (See Plate XXVIII.)

Note.—The above three sections were all kept at the temperatures specified for a period of fifteen minutes.

THE 1.46 PER CENT. CARBON STEEL NO. 1290 (AS CAST).

The section as cast consisted as usual of pearlite with sectional triangles marked out in cementite, indicative of cubic crystallisation. Plate XXIX. shows a section heated up to 750°C . and quenched. The pearlite has changed to hardenite, but the cementite (dark etching) remains *in situ*, apparently little changed.

Quenched from 810°C .—This section shows light streaks of cementite still undissolved and white patches of austenitic hardenite on a dark ground-mass of troostitic material “let down” from hardenite in the manner previously described. (See Plate XXX.)

Quenched from 868°C .—This section much resembles the last, except that more cementite has dissolved. (See Plate XXXI.) This section was kept at the temperature named for twelve minutes.

Quenched from 942°C . after being kept at that temperature for fifteen minutes. The cementite has entirely dissolved (in fact the solution seems complete for this carbon about 920°C .) and the ground mass is austenitic hardenite, showing

here and there a martensitic structure. This section shows also very well the formation of troostitic areas from a series of centres owing to the heat traversing the neck from the main body of the steel. (See Plate XXXII.)

THEORETICAL CONSIDERATIONS.

In presenting this preliminary note the authors wish to point out that during a research, involving the preparation of about 250 microsections, it has been clearly proved that the change of pearlite into hardenite occurs during a range of temperature not exceeding 3° C. In other words, 13 per cent. of B, Fe_3C , dissolves in or feebly combines with iron very rapidly, whereas say 10 per cent. of A, or cementite carbide proper, requires, as has been shown, a range of about 190° C. for its complete solution.

Hence, it is a subject for serious consideration. Is not the diffusion of A, carbide, into hardenite a normal act of solution, whilst the diffusion of B, cementite, into iron is rather of the nature of a reduction, producing a lower compound (hardenite) unique in its remarkable attenuation?

DISCUSSION.

Dr. WALTER ROSENHAIN (Teddington) said he considered the result described by Professor Arnold was obviously what one would have expected from the known properties of cementite and the curves in the equilibrium diagram, and he thought that therefore the paper did not require to be dealt with by him. In a hyper-eutectoid steel cementite was present in two conditions—laminated, and therefore finely divided in pearlite, and massive, as free cementite. Now if one tried the experiment of dissolving in water a finely divided substance and the same material in the form of large crystals, it would be found that a longer time or a higher temperature would be required for dissolving the large crystals. That alone would account for most of Professor Arnold's observations; but, further, it would appear from the equilibrium diagram that in order to dissolve the free cementite in the γ -iron it was necessary to raise the steel to a temperature above that of the curve representing the solubility of cementite in austenite, and that fact accounted for the higher temperature required in some of Professor Arnold's experiments. In fact there was no phenomenon which Professor Arnold had produced which suggested in the remotest degree that free cementite and cementite as contained in pearlite were different in character, or that the mode of their solution was essentially different.

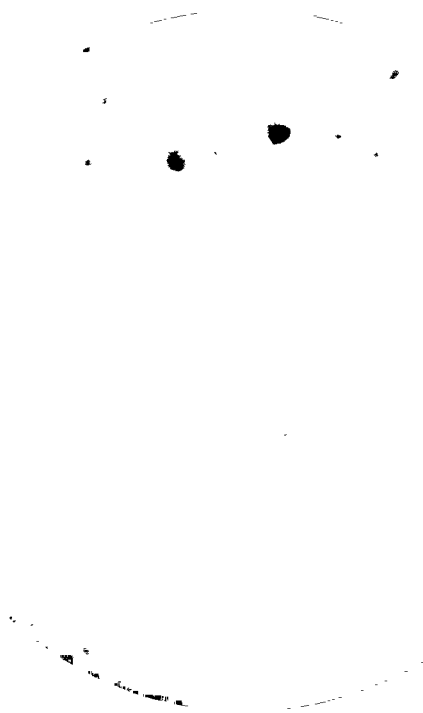
Dr. J. E. STEAD, F.R.S., Vice-President, said he was sorry the subject of the solubility of cementite in hardenite had not been dealt with at greater length, so as to make it perfectly clear as to what was really meant by the authors; it had been written in the fewest possible words, and such brevity was liable to lead to confusion. The term "saturated" applied to annealed steels was likely to be misleading, for such steels could not be regarded as saturated in any sense, and only became saturated, according to the definition of Dr. Arnold, in steels of pearlite composition after they had been heated and quenched from above the critical point. Pearlite contained two substances lying side by side and independent of each other. He would suggest that the alternative term "eutectoid," proposed by Professor Howe, was more satisfactory and useful, and it could be applied to steel with 0.9 per cent. carbon whether in the hardened or annealed condition. It corresponded by analogy to the eutectic of eutectiferous alloys. He (Dr. Stead), in a recent lecture before the West of Scotland Iron and Steel Institute, had endeavoured to remove the confusion existing in connection with the nomenclature of steel by giving the terms and definitions of the several authorities. He need not, therefore, further discuss the question of nomenclature.

On page 237 it was stated that "the quenchings, made in an ample tank of cold water and brine, did not occupy more than one second." It was not clear what was meant by that sentence. Did the authors mean that it occupied one second to transfer the



Carbon 1.05 per Cent. Heated to 741° C. and held there for 15 minutes and then quenched.
Magnified 180 diameters.

PLATE XXVII



Carbon 1.05 per Cent. Heated to 750° C. and held there for 15 minutes and then quenched.
Magnified 270 diameters.

PLATE XXVIII



Carbon 1.05 per Cent. Held at 755°C. for 15 minutes and then quenched.
Magnified 1180 diameters.

PLATE XXIX



Carbon 1.46 per Cent. Heated to 750° C. and then quenched
Magnified 320 diameters.

PLATE XXX

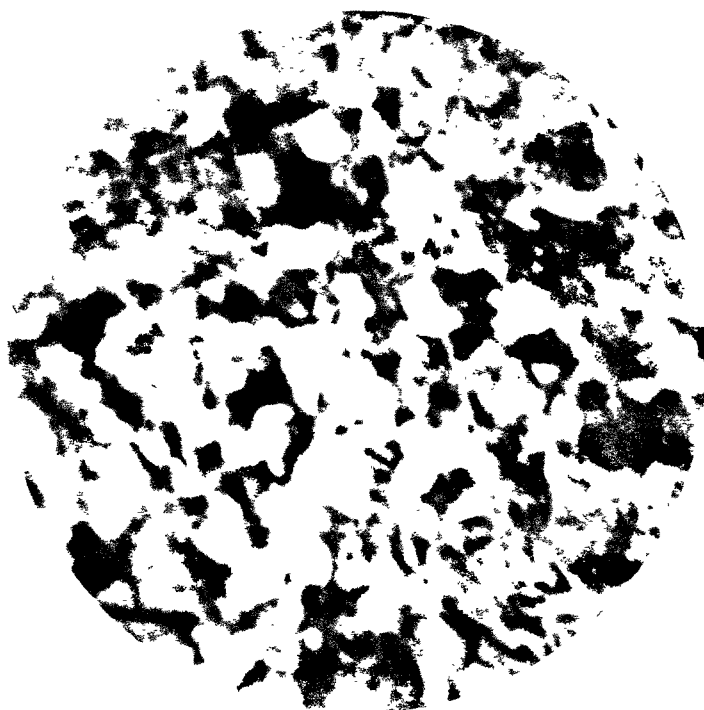


Carbon 1.46 per Cent. Heated to 810° C. and then quenched.
Magnified 320 diameters.

PLATE XXXI



Carbon 1.46 per Cent Heated to 868° C. and held there for 12 minutes and then quenched.
Magnified 320 diameters.



Carbon 1.46 per Cent. Held at 942° C. for 15 minutes and quenched.
Magnified 320 diameters.

pieces from the heating bath to the water, or that the steel was quenched right out in one second? If the latter interpretation was correct, then he was afraid practical men would deny that it was possible to quench to coldness pieces of steel of the size given from 900° to 1000° C. in such a short time. As a matter of fact, at the end of a second the steel would still be red-hot. White-hot steel when plunged into water remained visibly red for a few seconds. He believed that if it were possible instantaneously to chill low and medium carbon steels from a high temperature it would be possible to retain the iron partially in the γ -state. He hoped some day to bring before the Institute the result of work he had arranged to do in that direction.

The authors, in describing how their specimens were etched, said they used two different reagents, one a 5 per cent. solution of picric acid solution, or a 1 per cent. solution of nitric acid, as most convenient. What was meant by the expression "most convenient"? He understood it to mean the most suitable, but, as a matter of fact, he (Dr. Stead) had not found that either of those solutions were most suitable for developing the structure of hardened steels. The "polish attack" of Osmond, in his opinion, gave the best results; but that was not suitable excepting where there was no dust floating about the laboratory or polishing room. He had found a solution of 2 cubic centimetres of nitric acid in 98 cubic centimetres of amyl alcohol a rapid and useful reagent. The etching did not take more than one to two minutes. The enlarged photograph he exhibited (Fig. 1) was of steel of the same composition and hardened in the same way as that represented in Plate XXX. It showed the characteristic martensite structure. The illustration on Plate XXVII. resembled the sun with a sun-spot at one side of it, and did not show the structure which was undoubtedly in the steel itself, probably because the picric acid reagent employed for etching had not been in contact with the metal surface for a long enough period. The authors referred to cementite as white in one place and dark in another; the reason for that difference should be explained. Osmond had shown that when any thin plates of cementite were in relief, and the edges of the projecting particles were rounded and not quite flat, vertical rays of light falling on the rounded surfaces were reflected mainly outside and not into the microscope tube, and for that reason the cementite appeared to be dark although brilliantly white. Would the authors state whether the specimens represented in Plates XXIX. and XXX. were both illuminated by vertical rays, for the cementite was shown dark in one and white in the other? The terms martensite, austenite, and troostite, used by the authors for definite things, could only be interpreted as meaning substances containing martensite, austenite, and troostite. The authors on page 239 referred to a range of 3° C. at the change point Ar_{1-2-3} . It was generally maintained that that was a point and not a range. The best way to determine whether the change was spread over any interval was to take a piece of well-annealed steel, and heat it at constant tem-

perature above 700°C . at one end, leaving the other end well below 700°C . for a period of six hours, then cool in air, section it longitudinally, and polish and etch. Treated in that way, the critical point was shown as a well-defined junction without any gradation from one side to the other. The specimen shown (Fig. 2)



FIG. 1.—Hardened Steel corresponding with Plate XXX., etched with a 2 per cent. solution of nitric acid in isoamyl alcohol. Martensite structure in the inter-cementite portion of a cemented bar containing about 1.4 per cent. carbon, heated and quenched from 870°C . Magnified 500 diameters.

was an example of steel prepared in the manner described. It had been heated for several hours at one end to about 900°C . in a muffle furnace, whilst the other end projected into the air and was below redness. After the heating the bar was removed, cooled in air, sectioned, polished, and etched. The dark part represented the

portion of the steel which had been heated above the critical point Ar_{1-2-3} ; the lighter part represented where the heat was below the critical temperature. The white border to the dark portion represented the area where decarburisation had occurred during the heating.

The specimen illustrated several phenomena:—

First, that the critical point was really a point and not a range—a fact impossible of demonstration by the thermal recalescence method.

Secondly, that whilst at the critical temperature the carbide was in solid solution, just below that temperature the steel was most rapidly softened, due, as the microscope proved, to the rapid segregation or globularisation of the cementite plates of the pearlite.

Thirdly, that surface decarburisation of steel heated in air increased with the temperature above the critical point.

The quenching phenomena, referred to by the authors as remarkable,

Above Below
Critical Point. Critical Point.



Critical Point.

FIG. 2.—Tool Steel. $\frac{1}{2}$ -inch Bar. Carbon 0.85 per Cent.

really was so, but had been noticed by other observers. Osmond, who was the first to notice it, stated that in order to avoid having troostite mixed with martensite or hardenite, it was necessary to use small pieces of steel, as it was impossible to harden large pieces of carbon steels so as to have the inside portions free from troostite and as hard as the exterior parts; the reason being that the cooling of the central portion was slower than that of the exterior, and partly passed through the change point. In conclusion, he suggested that the authors should explain what was not quite clear, and introduce photographs showing the true structure of steels quenched from high temperatures.

Mr. C. A. EDWARDS (Middlesbrough) said he agreed with those who had criticised the statement that the change from hardenite to pearlite took place over a range of 3°C . There was, however, no objection if the authors intended the statement to refer to an experimental range of temperature. If the range was supposed to be theoretical, it would necessitate modifying the iron-carbon equilibrium diagram to a very serious degree.

SIR ROBERT HADFIELD, F.R.S., Past-President, thought that Dr. Stead's remarks concerning the hardening of steel rather gave the idea that in hardening a large mass of steel it was not possible to get as hard a surface in the interior as the exterior. It might, however, be mentioned that, for example, in hardening masses of steel such as projectiles, if desired, it was quite possible to maintain the interior as hard as the exterior. He mentioned that point to show that with certain kinds of steel hardness was not confined to the surface. That was not unnatural, because, for example, if they poured white iron into a mould two feet in diameter, they would get it almost as hard in the centre as on the outside. It therefore probably followed the same law existed more or less with regard to the hardening of steel.

MR. W. H. HATFIELD (Sheffield) said Dr. Rosenhain had stated that he did not know what hardenite was. He (Mr. Hatfield) did, and in fact the term was generally understood in Sheffield—and, after all, Sheffield counted in the world of iron and steel—to apply to the solid solution or an attenuated chemical compound corresponding in composition to Fe_{24}C when above the pearlite change point. It was a solid solution or sub-carbide which, when quenched, possessed extreme hardness. That was hardenite, and he put it to Dr. Rosenhain and others that they could not get any more adequate name for it. It really was "harden"-ite. Dr. Rosenhain had mentioned martensite, and asked whether they called it hardenite. He thought martensite had passed into the language of metallurgy as the adjective "martensitic," as the description of a structure, not as a constituent. At any rate, that was how it was understood in Sheffield. Dr. Stead had used the expression "martensitic structure," and Dr. Stead might be taken as exemplary in those matters of nomenclature. He (Mr. Hatfield) must, however, correct himself since Dr. Stead stated that the terms saturated and supersaturated made him creep. Why? The solutionists—and after all it was the solutionists that were the biggest antagonists of the theory of Professor Arnold—had their strongest support, in his opinion, in the very terms "saturated," "subsaturated," and "supersaturated" solution, which were Professor Arnold's terms, and obviously most applicable to alloys such as steel. If Dr. Stead meant an 0.89 per cent. carbon steel which had been annealed, it still remained a saturated steel—that was, that at higher temperatures it constituted a saturated solid solution. There was only one point further, and that was the question of the words sorbitic and troostitic. He thought it was fairly well understood now that those names applied to different gradations of the decomposition products resulting from the dissociation of hardenite into pearlite.

MR. W. J. FOSTER (Darlaston) said that he had on many previous occasions discussed the possibility of carbides of iron existing either in steel or cast iron, and he maintained point blank that, assuming due regard were paid to the integrity of the constitutional laws of

chemistry, there was no such thing as carbide of iron (Fe_3C) under any conditions whatever. In fact, the supposed chemical compound he regarded as nothing other than an artificially-manufactured formula, inasmuch as it was necessary to have a specific degree of carbon saturation, and also the cooling or heating temperature must be definite. He would like Professor Arnold to discuss that important question without prejudice either to the physical or chemical branch of science, and instead of concentrating the argument, as had been done in the past, on the properties of eutectoid steel under specific circumstances of heat treatment, &c., to divert his (Professor Arnold's) attention to the solubility of carbon in iron at higher temperatures, a subject dealt with by Mr. Foster in a paper which he read before the West of Scotland Iron and Steel Institute.

Before going further, he would be pleased if Professor Arnold would kindly consent to discuss the following preliminary questions :

(1) How would Professor Arnold or any of the Carbonists attempt to evolve the formula Fe_3C , simply on the usual constitutional laws as regards its valency ?

(2) How would the Carbonists attempt to separate the supposed Fe_3C from pure iron or cast iron saturated with carbon in the electric furnace, or the hot-blast furnace, the solution being allowed to cool down from extremely high temperatures over a long period ?

(3) How would they account for the decomposition of Fe_3C , or any other chemical compound due to a rising temperature, and also at the same time the formation of Fe_3C , by a reduction in temperature, with absolutely the same material involved, a phenomenon depending simply on the degree of saturation ?

(4) If a chemical compound were definitely known, its heat formation should also be indirectly or directly known. How did Carbonists explain the thermal properties of the alleged carbide, and what heat units would they attribute to its heat formation ? Was its formation attended by an exothermic or an endothermic reaction ?

(5) A chemical compound when formed must necessarily be stable over a considerable range of temperature without decomposition, assuming the general system were not interfered with by some external chemical action. How did Carbonists account for the gradual decomposition in a solution of liquid or solid carbon in iron ?

Probably the most useful nomenclature of carbon would be based on the degree of carbon saturation, or, in other words, the percentage of the carbon contents. Just as Mr. Foster had proved that the fracture of cast iron depended absolutely on the degree of carbon saturation, or its total carbon contents (other elements being considered to remain constant), the carbon contents and consequently the fracture depended entirely on the temperature. The same conditions applied to steel, therefore he contended there was good, solid, and substantial ground to work upon. Why, therefore, attempt to construe a simple problem into an unnecessarily difficult one ? Whatever might be the issue of that great question, the usefulness of Professor

Arnold's valuable researches of the past on the properties of steel would, however, be difficult to over-estimate.

CORRESPONDENCE.

Professor H. LE CHATELIER (Bessemer Medallist) wrote that he felt a certain degree of embarrassment in discussing the paper by Professor Arnold and Mr. Aitchison, owing to the vagueness of the definitions in the terms employed and the general lack of accuracy in the experimental methods. So far as could be seen, the essential results of the research differed in no wise from conclusions which had long since been accepted.

It was quite surprising to see so low a transformation temperature for these steels as 727° . That was surely an experimental error. In order to ascertain the temperature of the thermo-electric couple, it was necessary to plunge that couple into a mass kept at uniform temperature over a length equal to at least ten times the diameter of the couple, or else in a cover, as shown in the figure, over a length equal to ten times the diameter of the silica glass tube used as a protective cover. It was certainly in that direction that the explanation of the divergence noted between the temperature of transformation and that of hardening— 727° to 750° —was to be sought.

The authors were surprised to find the centre of their bars possessed a structure differing from that of portions nearer the surface, but that was a well-known fact. A carbon steel containing 1 per cent. of carbon, taken as a bar 10 millimetres in diameter and quenched somewhat above the end transformation point, gave martensite alone (Professor Arnold's "hardenite"). The same quenched in a bar of 50 millimetres diameter would give troostite only (Professor Heyn's "osmondite"). With intermediate dimensions the two constituents could exist side by side in the same section. The proportion of troostite would be larger in proportion to the size of the bar and to the amount of carbon it contained, and the closer the temperature of quenching approached the transformation point. Those well-known facts being borne in mind, the results obtained by the authors of the paper might be examined. The experiments on the steel containing 1.05 per cent. of carbon were absolutely normal. Quenching at 741° , that is to say, distinctly in the immediate neighbourhood of the transformation point gave, as it always did, troostite (osmondite); at 750° martensite (hardenite) was obtained, and the same result occurred at 755° . The darker colouration in the photograph arose from using too energetic a reagent—nitric acid instead of picric acid. Even with the latter, however, the martensite became blackened, provided the etching was continued long enough.

The remains of cementite described were not visible in the photographs, the clearness of which was quite insufficient for such an observation. On directly viewing the specimen, however, it was, as a

matter of fact, possible to detect plates of cementite, the sample being a hyper-eutectoid steel containing 1.05 per cent. of carbon, whereas the eutectoid steel only contained 0.85 per cent. of carbon.

The steel containing 1.46 per cent. of carbon appeared to have given at all temperatures, so far as it was possible to judge from the photographs, a more or less considerable proportion of troostite (osmondite). That arose from the fairly large dimensions of the sample, from its high percentage of carbon, and from its purity from other elements, particularly from silicon. With a sample half the size, martensite would certainly have predominated. In any case, the gradual solubility of cementite in the solid iron-carbon solution (austenite on heating) agreed with what had for a long time been known. The classic iron-carbon diagram showed the variation of that solubility in terms of the temperature. On the other hand, he (Professor Le Chatelier) did not understand what the authors meant by martensite-hardenite, as the photographs afforded no information on the subject.

Professor ARNOLD and Mr. AITCHISON, in reply to Dr. Rosenhain, dissented altogether from his parallel of the phenomena of saline solution with those of the solution of cementite in hardenite.

The solution of 13 per cent. of β or pearlite carbide was almost instantaneous and in the nature of a chemical reaction. The solubility of α or free cementite was really in the nature of a solution, fineness of division playing a very important part in the rapidity with which α -cementite dissolved in hardenite in a supersaturated steel. Speaking in round numbers, 13 per cent. of α -cementite required a range of 200° for complete solution against, say, 2° for the same quantity of β -carbide. Dr. Stead had discussed a preliminary note as though it was the actual paper dealing with the solubility of cementite in hardenite. With reference to Dr. Stead's suggestion that the authors should adopt Professor Howe's term "eutectoid," the authors regretted that they could not comply with that request. One of the authors published the term "saturated" eight years before Professor Howe proposed the new term without any consultation with the discoverer of the phenomenon. With reference to the duration of quenching, the edge of the micro-section was cold in about a second in spite of the opinion of Dr. Stead to the contrary. With reference to the term "point" as opposed to "range," here again the authors disagreed with Dr. Stead. The actual duration of a transformation was best described as its "amplitude." The term range had reference to the temperature, in degrees, intervening between the transformations.

The production of areas of troostitic pearlite by heat fed along the neck during quenching had never been recorded by Osmond, as stated by Dr. Stead, and in the absence of the neck attaching the thin micro-section to a larger mass of steel would not have taken place, since the transformation to hardenite would have been preserved throughout the section.

In reply to Mr. Foster the authors only wished to state that the existence of the definite carbide Fe_3C was well established, and one of them had already given Mr. Foster instructions how to isolate it, of which apparently he had failed to avail himself.

In the opening paragraph of Professor Le Chatelier's criticism he said that the methods employed exhibited a general lack of accuracy, although the results did not differ from accepted conclusions. Was it to be assumed that the conclusions reached by Professor Le Chatelier were similarly based on inaccurate methods? However surprised Professor Le Chatelier might be at the transformation of pearlite to hardenite, beginning at 727° or 2° before its ordinary temperature, such was the fact, and there was pyrometric accuracy insured at any rate to 1° .

The authors, however, absolutely denied that their conclusions as to the solubility of cementite in hardenite were generally admitted; for instance, Dr. Desch in his "Metallography" (p. 374) stated, "A tool steel containing 1.6 per cent. carbon quenched from 800° in ice water consists of pure martensite," a hopelessly inaccurate description.

It would be seen in the light of two papers to be read at the Leeds meeting, one the complete paper on the solubility of cementite in hardenite, and another on the solubility of hardenite in ferrite, that many of the criticisms on the preliminary note would fall to the ground.

THE CORROSION OF NICKEL, CHROMIUM, AND NICKEL-CHROMIUM STEELS.

By J. NEWTON FRIEND, J. LLOYD BENTLEY, AND WALTER WEST
(DARLINGTON).

THE effect upon the rate of corrosion of iron and steel produced by the introduction of alloying elements is a study which has been much neglected, although the influence of the same elements upon the general physical characteristics of the metal has in general been fairly completely dealt with.

The corrodibility of steel may be influenced in at least three different ways by the introduction of foreign elements, namely:—

1. A few elements, such as carbon, nickel, and silicon, yield compounds which offer a stout resistance to oxidation, and thus greatly enhance the stability of the metal towards corroding influences.

2. Some elements yield readily fusible alloys or compounds of variable melting points, which, during the solidification of the steel, tend to produce unequal distribution of the materials in the solid metal. This segregation is one of the most serious causes of galvanic activity and “pitting” with which the engineer has to contend.

3. Finally, a few elements, like sulphur, when present in steel, exist in the form of relatively oxidisable bodies which yield sulphureous acids, and thus greatly enhance the rate of corrosion of the metal when once it has begun. Now, although a good deal of isolated work has been done from time to time on the corrosion of nickel steels, most investigators have contented themselves with determining the relative rates of corrosion under only one, or at most two sets of conditions, the most usual being exposure to salt water and acid respectively. It was felt to be desirable to investigate more thoroughly the influence of nickel, and likewise to study that of chromium and of a mixture of nickel

and chromium, upon the corrodibility of steel—the last two branches of the subject having received but little attention hitherto, very few published data being extant. The authors are supplementing the work detailed in this memoir with several series of “long-period” tests, and hope, at a later date, to communicate the results and discuss them fully.

The steels experimented upon were kindly supplied in the form of bars by Messrs. Cammell, Laird & Co., of Sheffield, and were tool-turned and sliced into discs 0·7 centimetre thick and 2·8 centimetres in diameter, by the Darlington Forge Company. To both of these firms the authors wish to express their hearty thanks. The analyses of the steels, kindly supplied by Mr. B. Deby of Sheffield, were as follows:—

Analyses of Steels.

Steel No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Manganese per Cent.	Sulphur per Cent.	Nickel per Cent.	Chromium per Cent.
1	0·29	0·14	0·023	0·39	0·024	..	..
2	0·39	0·208	0·023	0·685	0·036	..	..
3	0·19	..	..	0·29	..	3·72	..
4	0·24	..	..	0·46	..	6·14	..
5	0·08	..	..	0·38	..	26·24	..
6	0·32	..	..	0·36	..	..	1·12
7	0·11	..	..	0·110	..	..	3·58
8	0·09	..	..	trace	..	..	5·30
9	0·552	0·127	..	0·41	..	3·40	1·00
10	0·54	..	..	0·58	..	3·5	1·12

It will be observed that while the steels have not a perfectly uniform composition with respect to the alloying elements, other than nickel and chromium, the discrepancies are relatively small and of minor importance compared with the range of nickel and chromium covered. Any results obtained with these, therefore, may probably be regarded as reliable. The discs of steel were carefully polished with emery-paper, weighed, and subjected to corroding influences as follows:—

1. TAP-WATER TESTS.

The discs were laid flatwise on a circular sheet of paraffin wax in a glass crystallising dish, as shown in Fig. 1, covered

with tap water to a depth of 6 centimetres, and kept in a dark cupboard to prevent any irregularity of corrosion consequent upon unequal illumination. The paraffin served to reduce to a minimum the possibility of galvanic action, and also

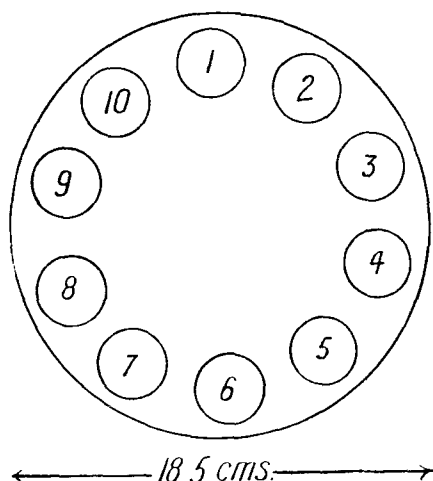


FIG. 1.

prevented the corrosive action of the silica—always observed if iron lies for any length of time in direct contact with glass. After sixty-four days the discs were removed, cleaned, and weighed, the loss in weight being taken as a measure of the corrosion. The results were as follows:—

Corrosion of Steels in Tap Water.

Steel No.	Nickel per Cent.	Chromium per Cent.	Original Weight. Grammes.	Loss in Weight Grammes.	Corrosion Factor.
1			35.6201	0.0961	100
2			37.4186	0.1038	108
3	3.72		33.5506	0.0798	83
4	6.14		30.1416	0.0666	69
5	26.24		33.4796	0.0488	51
6		1.12	28.7101	0.0817	85
7		3.58	28.6826	0.0558	58
8		5.30	31.1996	0.0400	43
9	3.4	1.00	30.8926	0.0736	77
10	3.5	1.12	31.5880	0.0844	87

2. SEA-WATER TESTS.

This series was conducted in a precisely similar manner to the previous one, save that the tap water was replaced by sea water taken from Bridlington Bay. The authors desire to acknowledge the kindness of Miss Agnes Harrison in obtaining and forwarding this to them. After sixty-four days, the loss in weight of the steels was found to be as follows:—

Corrosion of Steels in Sea Water.

Steel No.	Nickel per Cent.	Chromium per Cent.	Original Weight. Grammes.	Loss in Weight. Grammes.	Corrosion Factor.
1	...	...	34.4619	0.1136	100
2	...	...	37.5729	0.1196	105
3	3.72	...	30.9664	0.0886	77
4	6.14	...	32.9744	0.0906	79
5	26.24	...	30.2324	0.0516	45
6	...	1.12	28.7259	0.0686	60
7	...	3.58	25.9639	0.0291	26
8	...	5.30	30.9149	0.0261	23
9	3.4	1.00	30.6344	0.0936	82
10	3.5	1.12	29.1314	0.1026	90

3. SULPHURIC ACID TESTS (0.05 per Cent.).

These results were obtained in an exactly similar manner to the preceding, the corroding liquid being 0.05 per cent. sulphuric acid (that is 0.5 gramme of acid in 1000 grammes of solution with water). The results obtained after sixty days' exposure are given in the accompanying table:—

Corrosion of Steels in 0.05 per Cent. Sulphuric Acid.

Steel No.	Nickel per Cent.	Chromium per Cent.	Original Weight. Grammes.	Loss in Weight. Grammes.	Corrosion Factor.
1	...	...	37.9886	0.1594	100
2	...	...	37.2552	0.1560	98
3	3.72	...	32.2582	0.1350	85
4	6.14	...	31.8352	0.1320	82
5	26.24	...	31.4352	0.0860	54
6	...	1.12	29.2676	0.1134	71
7	...	3.58	29.9346	0.1088	68
8	...	5.30	30.8742	0.1086	68
9	3.4	1.00	30.8136	0.1394	87
10	3.5	1.12	32.4194	0.1492	93

4. SULPHURIC ACID TESTS (0·5 per Cent.).

These experiments were similar to the preceding ones, the acid being of the strength 0·5 per cent. by weight. The results obtained after fifty-three days' exposure were as follows:—

Corrosion of Steels in 0·5 per Cent. Sulphuric Acid.

Steel No.	Nickel per Cent.	Chromium per Cent.	Original Weight Grammes.	Loss in Weight Grammes.	Corrosion Factor
1			34·4266	0·9608	100
2			36·6388	2·4878	259
3	3·72		32·1346	0·5308	55
4	6·14		31·9370	0·6042	63
5	26·24		31·9886	0·0770	8
6		1·12	28·8042	2·1420	223
7		3·58	28·9772	0·5830	61
8		5·30	30·6176	0·7514	78
9	3·4	1·00	30·9126	1·2722	132
10	3·5	1·12	33·6036	3·9672	413

5. ALTERNATE WET AND DRY TESTS.

These experiments were carried out in a large iron thermostat, of the dimensions and shape shown in Fig. 2, the metal

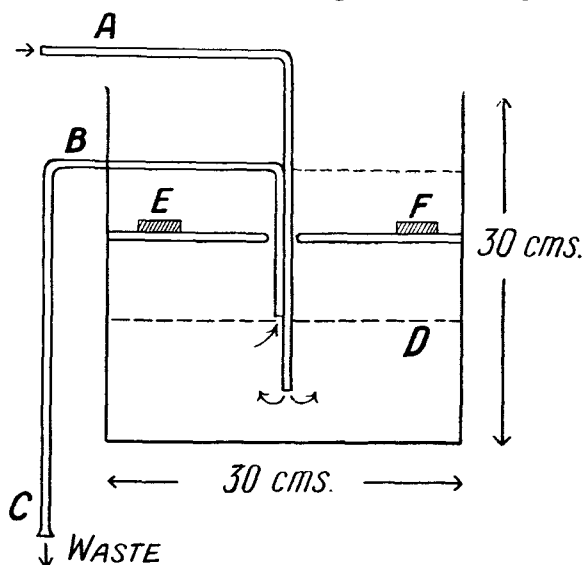


FIG. 2.

discs (E, F, &c.) being laid, as before, in a circle flatwise on a sheet of paraffin wax. Water entered slowly by tube A, and being admitted to the centre of the apparatus, affected all the discs equally. The paraffin disc was perforated by numerous small holes, and rested on a similarly perforated iron disc, to enable it to bear the weight of the steels. When the water reached the level B, it was quickly syphoned off automatically by BC, and the level fell to D. It then began to fill again. In this way the metal discs were exposed to alternate wet and dry, the process of filling the thermostat requiring two hours each time. A loosely fitting cover was placed on the top to keep out dust, and to maintain darkness within, in order to prevent, as before, any irregularity of corrosion consequent upon unequal illumination. The results obtained after an exposure extending over fifty-two days were as follows:—

Corrosion of Steels exposed to alternate Wet and Dry.

Steel No.	Nickel per Cent.	Chromium per Cent.	Original Weight. Grammes.	Loss in Weight. Grammes.	Corrosion Factor.
1	...	...	38.5536	0.2706	100
2	...	...	38.7170	0.2720	100
3	3.72	...	28.3870	0.1165	43
4	6.14	...	31.8660	0.0985	36
5	26.24	...	30.8160	0.0220	8
6	...	1.12	28.5846	0.2512	93
7	...	3.58	28.3886	0.0806	30
8	...	5.30	30.8406	0.0556	21
9	3.4	1.0	29.8748	0.1274	47
10	3.5	1.12	32.7956	0.1404	52

DISCUSSION OF THE RESULTS.

In order to facilitate the discussion of these results, the following table has been drawn up in which the corrosion factors of the steels as obtained by each method are given:—

Corrosion Factors of Nickel, Chromium, and Nickel-Chromium Steels.

Steel No.	Nickel per Cent.	Chromium per Cent.	Corrosion Factor for—				
			Tap Water.	Sea Water.	Wet and Dry.	0.05 per Cent. Acid	0.5 per Cent. Acid
1	...	..	100	100	100	100	100
2	...	..	108	105	100	98	259
3	3.72	..	83	77	43	85	55
4	6.14	...	69	79	36	82	63
5	26.24	...	51	45	8	54	8
6	...	1.12	85	60	93	71	223
7	...	3.58	58	26	30	68	61
8	...	5.30	43	23	21	68	78
9	3.4	1.0	77	82	47	87	132
10	3.5	1.12	87	90	52	93	413

A careful study of the above table reveals a number of highly interesting facts. These may be summarised as follows:—

1. The corroding media may be divided into two groups, namely acid and neutral, and the results obtained are usually very different in the two cases. Very dilute acid resembles the neutral corroding media in its action. This we might expect, since the so-called neutral media (tap water, sea water, &c.) always contain a minute quantity of acids, such as carbonic.

2. Acceleration tests as usually carried out with sulphuric acid, yield very misleading results as to the general corrodibility of the metals tested. Thus, for example, the two standard steels corroded at almost identical rates when exposed to tap water, sea water, wet and dry, and to 0.05 per cent. sulphuric acid. But in the 0.5 per cent. acid the second steel corroded some two and a half times as rapidly as the first. Very similar discrepancies occur with steels Nos. 6, 9, and 10, the last named corroding more than three times as much as steel No. 9, although in the other tests the two steels behaved similarly, as we should expect from their analogous compositions.

These observations are in perfect harmony with those of Frazer,¹ who found that whilst samples of basic and acid steel of analogous composition corroded at practically identical

¹ *Journal of the West of Scotland Iron and Steel Institute*, 1907, vol. xiv. p. 82.

rates under ordinary conditions, yet when exposed to the action of dilute sulphuric acid the results were most irregular, in one case the acid steel corroding five times as rapidly as the basic steel. The results of the Corrosion Committee of the British Association emphasise the same fact,¹ and C. M. Chapman,² working in America, has been led to similar conclusions.

The explanation is not far to seek. Two opposing forces are called into play when steel is immersed in a corroding medium, namely:—

(a) Galvanic activity between the relatively incorrodible portions and the easily oxidisable ferrite, the latter functioning as the anode and the former as the cathode. The corrosion of the ferrite is thus accelerated. Amongst the incorrodible materials we must class cementite, in ordinary steel, and in the steels studied in this memoir we have the various complexes of iron, carbon, nickel, and chromium, all of which function cathodically.

(b) On the other hand these incorrodible materials offer a very effective mechanical protection against corrosion by preventing the corroding medium from coming into direct contact with the ferrite, and thus tend to protect the metal from corrosion.

A moment's consideration will show, however, that by intensifying the corrosive media, as, for example, by the employment of sulphuric acid, the two forces mentioned above will not be affected to the same degree, and that the results obtained will not be the same as they would be had the metal been exposed to a less intense action for a longer time. Consequently the two methods are not strictly analogous.

The honeycombed appearance of the surface of steels Nos. 2, 6, and 10, was so pronounced as to render doubt impossible as to the intensity of the galvanic action which had taken place. The fact that no nickel and chromium could be detected in the corroding acid shows that these metals were

¹ *Chemical News*, 1911, vol. civ. pp. 142, 155; see also criticism by Friend, *ibid.*, p. 164.

² Paper read before the American Society for Testing Materials, June 28, 1911.

constituents of the cathode, and the excessive corrosion of these steels makes it clear that the galvanic activity was stimulated out of all proportion to the mechanical protection afforded by these metals.

3. From the results with steels Nos. 6, 7, and 8, in 0·5 per cent. acid, it would appear that there is an optimum concentration of chromium which yields the maximum resistance to acid attack, and that if this amount be exceeded (as in steel No. 8) the steel becomes less permanent. This is thoroughly in accordance with the results obtained by Hadfield,¹ and more recently by Monnartz.²

4. In neutral corroding media the resistance offered to corrosion apparently rises with the percentage of chromium. This is particularly the case for salt water, and the employment of chromium steels in the construction of ships would appear to be fully justified on this ground alone.

5. Nickel steels appear to be resistant to acid and neutral corroding media alike, the resistivity increasing with the percentage of nickel. The permanence of the 26 per cent. nickel steel towards 0·5 per cent. acid is particularly noteworthy.

6. The corrosion factor does not appear to be a purely additive quantity. Thus, for example, in exposure tests with tap water, the corrosion factors of steels Nos. 3 and 6 respectively are 83 and 85. It might be expected, therefore, that since the 3·72 per cent. of nickel and the 1·12 per cent. of chromium each separately yield the same protection, by having both together in the steel the same result should accrue as by either doubling the nickel or the chromium content alone. This, however, is not the case, as is evident from a consideration of the results obtained with steels Nos. 4, 7, 9, and 10. Similar conclusions are arrived at from the sea water, and other tests with the same steels.

Whilst these results are extremely important they are not final. They have only been obtained from experiments carried out at room temperature (12° C. to 15° C.), and the period of testing has not exceeded sixty-four days. The work is being continued at different temperatures and with long

¹ *Journal of the Iron and Steel Institute*, 1892, No. II, p. 92.

² *Metallurgie*, 1911, vol. viii, pp. 161, 193.

period tests, so that the conditions may resemble as closely as possible those actually experienced under working conditions. In conclusion, the authors wish to urge the necessity of determining the corrosion of iron and steel under conditions closely similar to those to which the metal will be subjected in practice, otherwise the results will be unreliable and lead to much confusion.

THE MECHANISM OF CORROSION.

BY J. NEWTON FRIEND, WALTER WEST, AND J. LLOYD BENTLEY
(DARLINGTON).

ONE of the main causes of the fascination attaching to the study of corrosion is that new phenomena are constantly appearing which cannot be reconciled with our old stereotyped theories, and necessitate, therefore, a constant re-adjustment of our ideas. In a recent communication to this Journal¹ a list was drawn up of the more important factors influencing the rate of corrosion of relatively pure iron at ordinary temperatures; and attention was drawn to the extreme care required in order to carry out two exactly similar experiments from which reliable conclusions may be safely drawn. During the past year the authors have studied a few of the factors requiring consideration, in greater detail. The results obtained and embodied in this memoir serve both to corroborate and to extend our earlier work.

1. THE CORROSION ZONE.

When a plate of iron is suspended in stationary water, the surface of which has free access to the air, the layers of water in contact with the metal yield up their dissolved oxygen and thereby induce corrosion. Fresh supplies of oxygen from the surrounding layers of water now diffuse towards the metal, and in the course of a few hours an equilibrium is set up, the amount of oxygen diffusing towards the metal being exactly equal to that absorbed in producing rust. This condition is shown in Fig. 1, where AB is the metal plate, and ACDE represents what may be termed the *Corrosion Zone*, the amount of dissolved oxygen in the water gradually decreasing as any point on the circumference of the zone, say E to the metal itself at B, is passed. At all points

¹ Friend, *Carnegie Scholarship Memoirs*, 1911.

outside the zone, such as F, G, &c., the amount of dissolved oxygen remains constant. The actual size of this zone must depend upon a large variety of factors, all of which may be grouped under two headings, namely:—

1. The rate at which oxygen can diffuse towards the metal, and

2. The rate at which the metal can absorb the oxygen.

The former of these factors is influenced by the pressure and composition of the air in contact with the surface of the

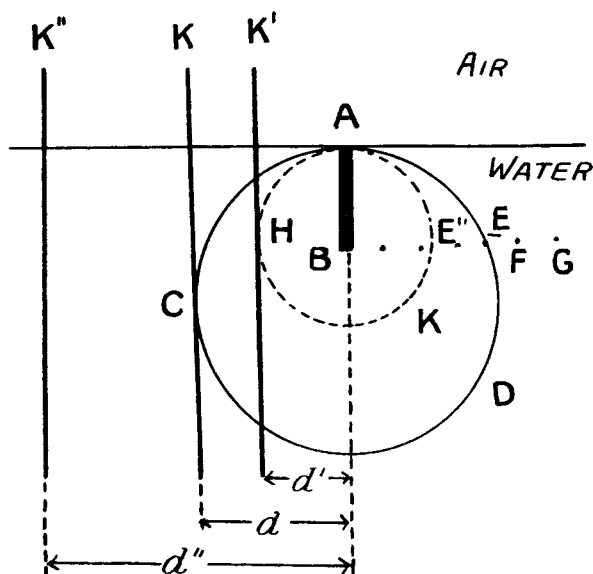


FIG 1.

water, and also by the solubility of oxygen in the water—a function of the temperature and purity of the latter.

As regards the rate of absorption of oxygen by the metal itself, the influence of temperature and light, the composition of the metal, its physical condition, and the effect upon it of any impurities in the water, have to be considered. Clearly the more corrodible the metal, the larger is the corrosion zone, other things being equal. When, on the other hand, the metal is protected by paint, zinc, or tin, the corrosion zone may be negligibly small.

Now it follows that unless due allowance is made for this, a serious source of error is liable to creep into experiments designed to throw light upon the relative corrodibilities of different pieces of metal.

If AB be suspended in a tank, the side K of the latter must not be so near as to come within the corrosion zone as at K' or the metal will not corrode at its maximum rate. Once beyond this zone, however, it is immaterial how far off the side is, the rate of corrosion of the plate being the same whether the side is at K or K''. Suppose, now, there are two plates, one say of nickel steel and one of ordinary carbon steel, and it is wished to determine their relative rates of corrosion. Assume that the nickel steel corrodes only half as rapidly as the carbon steel. If the corrosion of the latter is taken as 100, that of the former will be 50, and the corrosion zone of the carbon steel may be represented by the curve ACDE, and that of the nickel steel by the broken curve AHK. Suppose these plates are suspended in a tank at a distance d' from the side (K'). They are then under what appear to be precisely similar conditions. In reality such is not the case, however, for whilst the nickel steel can corrode at its maximum rate because K' lies without its corrosion zone, the carbon steel cannot corrode more than about 70 per cent. of its maximum amount since K' lies so far within its corrosion zone. Hence the relative corrosions as determined in this way would be:—

$$\frac{\text{Corrosion of carbon steel}}{\text{Corrosion of nickel steel}} = \frac{70}{50} = \frac{100}{71}$$

If, now, we repeat the experiment, suspending the two plates at a distance d from the side K, the nickel steel corrodes at the same rate as before, but the carbon steel is now able to corrode at its maximum rate. The observed rates of corrosion are, in consequence, 100 to 50.

There can be no doubt that many of the curious variations obtained by different investigators when conducting experiments of this kind are traceable to some such cause as this.

In order to gain some idea as to the magnitude of the corrosion zone, some pieces of Kahlbaum's pure iron foil were

cleaned with emery-paper, weighed, and suspended by means of glass hooks in earthenware troughs of water at varying distances from the sides. The plates measured 3 inches in length and 2·5 inches in breadth, and were attached to the hooks by paraffin wax (see Fig. 2), so that the disturbing corrosive action of the silica of the glass was removed. After nine days the plates were cleaned and weighed, the loss in weight being taken as a measure of the corrosion. The results were as follows:—

Distance of Plate from Side. Inches.	Initial Weight of Plate. Grammes.	Loss in Weight. Grammes	Corrosion Factor.
5	8·4214	0·1546	100
3	8·6286	0·1574	102
2	8·6264	0·1340	87
1	8·3866	0·1266	82
0·5	8·1574	0·1418	92
0·25	8·1256	0·1640	106

From the above table it may be gathered that:—

1. The maximum corrosion is reached when the plate is not less than 3 inches from the side of the trough, that observed at 5 inches distance being the same (within experimental error).

2. When the iron is very close to the side the rate of corrosion begins to increase abnormally. This came as a great surprise, but the next series of experiments showed that

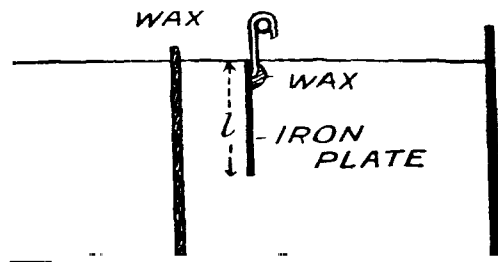


FIG. 2.

the anomaly was due either to the silica of the glaze or some other corroding material dissolving out of the pores of the

earthenware. In the chemical activity of the apparently neutral walls of a containing vessel, therefore, a serious source of error may lie.

In order to avoid this disturbance, a similar series of iron plates were suspended, this time in the centre of the troughs and sheets of paraffin wax fixed at varying distances from them, as shown in Fig. 2. After ten days of exposure the following results were obtained:—

Distance of Plate from Side. Inches.	Initial Weight of Plate. Grammes.	Loss in Weight. Grammes.	Corrosion Factor.
10	8.6041	0.1585	100
5	8.0067	0.1566	99
2.5	7.8715	0.1334	84
1.2	8.5880	0.1302	82
0.6	8.4915	0.1247	79

Evidently, therefore, the closer the metal is suspended in still water to the side of the containing vessel, the less is it able to corrode.

These experiments were now repeated, using two plates of paraffin wax in each case, the plate of iron being suspended midway between them. After nineteen days the plates were cleaned and weighed with the following results:—

(Area of plate = 6×6 centimetres.
Length of plate = $l = 6$ centimetres.)

Distance of Plate from Sides.		Initial Weight of Plate. Grammes.	Loss in Weight. Grammes.	Corrosion Factor.
In Centimetres.	In Terms of Length of Plate.			
12	$2l$	6.0760	0.1940	100
12	$2l$	6.1010	0.1970	
6	l	5.9530	0.1990	101
3	$\frac{1}{2}l$	5.9530	0.1780	91
1.5	$\frac{1}{4}l$	6.4219	0.1437	73
0.75	$\frac{1}{8}l$	6.2782	0.0776	40

From this it is evident that the plates under the particular conditions of the experiments should not be suspended nearer

than a distance measured by their length l , if the maximum corrosion is to be obtained. This, of course, assumes that the sides of the vessel are chemically inert.

If, now, the inert paraffin sheet is replaced by a second metal plate of similar corrosive properties, it will be evident that twice the above distance must be left between the two if maximal corrosions are to be obtained in either case. This was confirmed in part by suspending two plates of iron in each trough at varying distances from one another, and determining their loss in weight after seven days. The plates were 2.5 inches square, and were suspended in a similar manner to the preceding. The results were as follows:—

Distance of Plates from each other. Inches.	Initial Weight of Plates. Grammes.	Loss in Weight. Grammes.	Mean Loss. Grammes.	Corrosion Factor.
Single Plate ¹	7.0136	0.0741 }	0.0752	100
Single Plate ¹	7.0370	0.0762 }		
4	{ 6.3968	0.0700 }	0.0708	94
	{ 6.4658	0.0715 }		
2	{ 6.4704	0.0606 }	0.0611	81
	{ 6.3933	0.0615 }		
1	{ 6.4428	0.0600 }	0.0610	81
	{ 6.2853	0.0620 }		
$\frac{1}{2}$	{ 6.8088	0.0630 }	0.0645	85
	{ 6.8744	0.0659 }		

From this table it is clear that where the plates were suspended at a distance of $\frac{4l}{2.5} = 1.6$ times their length apart, the maximum corrosion is not attained. Evidently, therefore, in order to obtain trustworthy results for the relative corrosions of various irons and steels by immersion in still liquids in troughs, the plates must be suspended considerably further apart than has hitherto been customary. With painted, galvanised, and tinned plates, of course the case is quite different, for, owing to the slow rate of corrosion, the corrosion zone is correspondingly reduced and the plates may be much nearer together. In moving water, likewise, the plates may

¹ These were single plates in separate troughs. Unfortunately the authors did not possess a sufficient number of larger troughs which would enable them to place two plates in any one trough at a greater distance than 4 inches without incurring risk of interference from the sides of the vessel.

be nearer, but in both of these cases it is better not to have them too close together, or films of dust may spread from plate to plate and thus galvanically connect them and induce serious corrosion. This was probably the case with the last two plates, at half an inch distance, as given in the above table, and which show a marked and unequal increase in their corrosion.

In the above experiments the troughs were kept in the dark during the periods of exposing the plates, in order to prevent the disturbing influences of unequal illumination. In actual practice the influence exerted by suspending two plates close together would be even greater than that indicated in the above experiments, since one plate would cast a shadow on the other and thus withdraw from it the stimulating action of light. The isolated plates, on the other hand, would suffer no retardation in this way.

2. THE MECHANISM OF CORROSION.

When layers of rust are analysed, they are frequently found to contain at least traces of ferrous iron.¹ This is quite in harmony with the acid theory of corrosion, according to which the first stage in the corrosion of iron consists in the formation of a ferrous salt, which later undergoes oxidation to the ferric condition, yielding hydrated ferric oxide or rust.

The numerous analyses of rust usually teach us but little beyond this, however, inasmuch as the exact conditions under which the various samples of metal rusted were unknown. It occurred to us that, if we allowed pure iron to rust under a series of well-defined conditions, and then analysed the rust produced, fresh light might be thrown upon some of the hitherto obscure problems. To this end Kahlbaum's pure iron foil was always employed, as its composition has been proved by repeated trials to be most uniform, and hence to be particularly suitable for the purpose in hand.

¹ Calvert, *Chemical News*, 1871, vol. xxiii., p. 98. Weinwurm, *Chemiker Zeitung*, 1893, vol. xvii., p. 101. Tilden, *Transactions of the Chemical Society*, 1908, vol. xciii., p. 1358. Steel, *Journal of the Society of Chemical Industry*, 1910, vol. xxix., p. 1141, &c.

The Influence of Light.—Attention has already been drawn in previous papers¹ to the fact that light greatly accelerates the rate of corrosion of iron. An engineer criticised this statement shortly after publication, stating it to be contrary to experience, instancing an iron bridge, the under and shaded portions of which were more corroded than the upper ones. This illustrates the difficulty experienced by practical men of realising how essential it is that conditions shall be exactly comparable before trustworthy conclusions may be drawn. By shutting out the light in the above case, the free access of fresh, warm, and dry air was also cut off, so that the under portion of the bridge was always moist, whereas the upper and exposed places were usually dry. Clearly the effect of constant moisture must far outweigh the purely stimulating action of light, since a dry surface cannot rust.

The question which now arises is: How does the light accelerate corrosion? This it may do in one or both of two ways:—

1. By accelerating the initial stage of corrosion, namely, the oxidation of the metal to the ferrous condition

. Reaction 1.

2. By accelerating the second stage of corrosion, namely, the oxidation of the ferrous iron to ferric (rust)

. Reaction 2.

Solutions of ferrous sulphate, slightly acidified with dilute sulphuric acid, were placed in similarly shaped glass bottles, some of which were transparent, others being rendered opaque by a thick coating of paint on the outside. These were kept at a uniform temperature in a glass water-bath and exposed to diffused sunlight. After varying intervals of time, portions of the solutions were removed and the relative proportions of ferrous and ferric iron determined by titration with bichromate. At the beginning of the tests there was no ferric iron present, hence the figures in the third column of the table give the relative rates of oxidation of the ferrous sulphate in the light and dark respectively:—

¹ See Friend, *loc. cit.*

No.	Condition.	Length of Exposure (Days).	Ferric Iron as per Cent of Total Iron.
1	{ Light	15	14.4
	{ Dark	15	13.0
2	{ Light	44	26.8
	{ Dark	44	23.4
3	{ Light	53	28.4
	{ Dark	53	24.6
4	{ Light	71	39.3
	{ Dark	71	34.8
5	{ Light	71	30.3
	{ Dark	71	26.8

Clearly the light stimulates the oxidation of ferrous iron to the ferric condition—but only relatively slightly. Whilst, therefore, during ordinary corrosion of iron the light undoubtedly stimulates Reaction 2 (above), it would seem that this acceleration is too small to wholly account for the increased corrosion actually observed. Probably, therefore, light also accelerates Reaction 1, namely, the oxidation of the metal to the ferrous condition. In order to test this, plates of iron measuring 4 by 6 centimetres in area were exposed in beakers of water in such a manner that their four corners rested in contact with the sides and bottom of the beakers. Each beaker held one plate and 100 cubic centimetres of distilled water. Four of these, Nos. 1 to 4, were placed in the light, and an equal number (Nos. 5 to 8) in a dark cupboard. Each week one beaker was taken from the light and dark respectively, the loss in weight of iron and the amounts of ferrous and ferric oxide produced being quantitatively determined. The results are given in the following table, the weights of iron being expressed as grammes:—

No.	Condition.	Time Days.	Initial Weight of Plate.	Weight of Ferrous Iron.	Total Loss in Weight.	Percentage of Ferrous Iron.
1	Light	8	3.4994	nil	0.0326	nil
5	Dark	8	4.1144	nil	0.0276	nil
2	Light	15	3.9894	0.0011	0.0641	1.8
6	Dark	15	3.8162	trace	0.0521	trace
3	Light	23	4.2014	0.0101	0.1029	9.8
7	Dark	23	3.9014	0.0011	0.0709	1.5
4	Light	29	4.1522	0.0178	0.1278	13.9
8	Dark	29	3.8118	nil	0.0800	nil

From the above it may be gathered:—

1. That the plates exposed to the light rusted more rapidly than those in the dark—confirming earlier work.

2. An appreciable amount of ferrous oxide is produced on prolonged exposure to daylight.

3. No appreciable quantities of ferrous oxide are produced in the dark—under the particular conditions of the experiment.

Evidently, therefore, light not only accelerates the oxidation of ferrous iron to ferric, as has been seen, but it has a more pronounced accelerating influence on the initial oxidation of metallic iron (Reaction 2, above), so that the formation of ferrous oxide outstrips that of ferric. In the dark, however, the two reactions apparently proceed at practically the same rate, so that the ferrous oxide is oxidised to rust as rapidly as it is formed.

As time goes on the accumulation of rust and ferrous oxide becomes so thick that light cannot easily penetrate, and the corrosion proceeds as if the metal were in the dark. Hence the reaction slows up, and the percentage of ferrous iron in the rust begins to fall. This accounts for the relatively small quantities of ferrous iron found in thick rust deposits, even when metallic iron still remains. When all the iron has been oxidised, of course the ferrous oxide slowly follows suit, until even the last traces may be oxidised.

There can be little doubt that numerous other factors, such as galvanic action, temperature, and nature of the corroding medium, will affect the relative proportions of ferrous and ferric oxide produced during the corrosion of iron. Experiments are now in progress with a view to determining the respective values of each of these factors, and the authors hope to communicate the results in a later memoir.

The authors have pleasure in acknowledging the receipt of a grant from the Chemical Society, London, which is enabling them to carry out these investigations.

DISCUSSION.

Professor H. E. ARMSTRONG (London), referring to Dr. Friend's paper, said he was not at all satisfied that light promoted rust, although there had been an increase of rust in the authors' experiments. Theoretically the action of light might conceivably affect it, but he was inclined to think that the effect produced in the case of those experiments was due to differences of temperature rather than to other causes.

THE INFLUENCE OF CARBON ON THE CORRODIBILITY OF IRON

BY C. CHAPPELL, B.MET. (HONS.), SHEFFIELD

INTRODUCTION.

DURING the past few years the subject of the corrosion of iron and steel has been receiving a well merited and rapidly increasing attention. Despite this fact, however, it is often difficult to obtain reliable information as to the specific influence exerted upon the corrosion of these metals by varying proportions of alloying elements. Especially is this the case with regard to the influence of increasing percentages of carbon on the corrodibility of iron. In view, therefore, of the prime importance of carbon in the metallurgy of steel, investigations have been carried out to ascertain the nature and extent of this influence.

Two main elements of uncertainty enter more or less into practically all the experimental results that are available in connection with this question—the lack of chemical purity in the steels employed, and the negligence of precautions to ensure that the steels shall be in a uniform condition of treatment before testing.

Special attention has been paid to these two features throughout the present paper, which will therefore constitute a basis from which the influence of other elements upon the corrodibility of steel may subsequently be individually and accurately determined.

GENERAL SCHEME OF INVESTIGATION.

A series of practically pure iron-carbon steels has been prepared. Suitable bars of each steel have been subjected to typical heat treatments, and their relative corrodibilities and other properties have been investigated in each of these

various states of heat treatment. By these means, not only has the influence exerted on these properties by variations in carbon percentage been determined, but also the influence of variations in the chemical and physical condition in which the carbon exists in these alloys, within the range of commercial treatments.

Microscopic investigations into the *modus operandi* of the corrosion of iron-carbon steels have also been made, and have been productive of much interesting and important evidence, despite the considerable difficulty of examining corroded surfaces at high magnifications.

PRODUCTION AND COMPOSITION OF THE STEELS.

The steels were all manufactured by the coke crucible process in the Metallurgical Department of the University of Sheffield. Six ingots were made, ranging from 36 lb. to 40 lb. in weight. The carbon contents ranged from 0.10 per cent. to 0.96 per cent. The materials employed throughout the series were Swedish bar-iron and charcoal. This method has previously proved itself by far the most satisfactory one for the production of iron-carbon steels of a high degree of purity. "Killing" was effected by aluminium in every case, and all the steels gave sound ingots.

The chemical analysis of the steels is given in Table I., together with the distinguishing number employed throughout the research for each steel.

It will be observed that in no case do the total impurities exceed 0.28 per cent.

TABLE I.—*Analysis of Steels.*

Steel. No.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Aluminium.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	0.10	0.019	0.091	0.030	0.011	0.02
2	0.24	0.037	0.072	0.028	0.015	..
3	0.30	0.030	0.094	0.021	0.012	...
4	0.55	0.053	0.100	0.020	0.017	0.03
5	0.81	0.048	0.168	0.028	0.016	...
6	0.96	0.018	0.133	0.027	0.014	0.02

TREATMENT OF STEELS.

Each ingot was rolled down so as to give about 4 feet of $\frac{3}{4}$ -inch round bar, and the remainder taken down to $\frac{5}{8}$ inch diameter. The treatments employed are briefly described in Table II., together with the letters used to denote the respective treatments.

TABLE II.—*Treatments and Characteristic Marks.*

Treatment.	Mark.
Rolled	R.
Normalised at 900° C., cooled in air	N.
Annealed at 950° C. for 20 hours, very slowly cooled in furnace	A.
Quenched from 800° C. in water	C.
Quenched from 800° C., tempered at 400° C.	D.
Quenched from 800° C., tempered at 500° C.	E.

DETAILS OF TREATMENTS.

Rolled.—Test-bars were turned from the $\frac{5}{8}$ -inch round bars as received from the mill.

Normalising.—This was carried out in a large gas muffle on the $\frac{5}{8}$ -inch size bars. These were put in at 800° C.; the temperature of the muffle fell to about 600° C., and was then gradually raised to 900° C. The bars were removed after twenty minutes at this temperature, and allowed to cool in air.

Annealing.—This treatment was carried out in a coal-fired annealing furnace according to the details given in Table II. The $\frac{3}{4}$ -inch round bars were employed for this treatment, so that the decarburised skin could be completely machined off in the lathe in preparing the test-pieces, and its influence thus eliminated from the subsequent tests.

Quenching.—The bars were heated in a Brayshaw salt-bath furnace to 800° C., allowed to remain at that temperature for fifteen minutes, and then rapidly quenched out in water at 15° C.

Tempering.—The quenched bars were heated up to the required temperature in a lead bath, maintained at that temperature for ten minutes, and then cooled in air.

It must be noted that in both the quenched and tempered

series the test-pieces were machined to slightly over the finished size before treatment. Any influence possibly exerted by the molten salt on the surface of the bar was subsequently obviated by the entire removal of the surface in reducing to the required finished size.

CORROSION TESTS.

Method of Experiment.

Test-bars, $4\frac{1}{2}$ inches long by $\frac{3}{8}$ inch diameter, were prepared from each steel in all states of treatment. Each bar was drilled at a distance of $\frac{1}{4}$ inch from one end, with a hole, $\frac{1}{8}$ inch in diameter, for suspension purposes. The suspension was effected by means of thin glass hooks passing through the centre of the corks closing the jars, as shown in Fig. 1. Separate jars were used for each test-piece, and free access by the air to the interior of the jar was carefully ensured in each case.

The test-bars themselves were polished in the lathe to a uniformly high degree of polish with fine emery paper.

The importance of having the specimens as nearly uniformly polished as possible is considerable, and must be insisted upon in comparative corrosion testing. The author has frequently found, during the microscopic examination of corroded surfaces, that the finest scratches from the polishing-block are often productive of more vigorous corrosion than occurs in any other portion of the specimen, even after several months' immersion in sea water. So that uniformity of polish, as the nearest practicable ideal, should receive careful attention in experimental corrosion research.

After polishing, the bars were accurately weighed, immersed in pure ether for at least an hour to remove all grease, dried in a vacuum desiccator, and then suspended in 700 cubic centimetres of filtered sea water, as shown in Fig. 1.

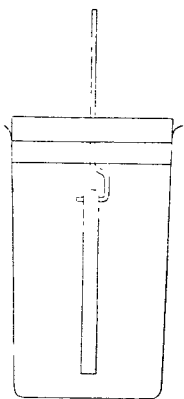


FIG. 1.—Method of Suspension.

This sea water was obtained from the Irish Sea, and its analysis is given in Table III.

The room in which the tests were carried out was well lighted, but situated so that no direct sunlight entered it. Variations in temperature were largely atmospheric, as the room was not artificially heated.

TABLE III.—*Analysis of Sea Water Employed.*

Specific gravity at 12° C., 1.0240.

1000 parts by weight of sea water contain :—

	Parts by Weight.
Sodium chloride	27.20
Magnesium chloride	2.95
Magnesium sulphate	1.84
Calcium sulphate	1.20
Potassium chloride	0.77
Calcium carbonate	0.11

After 91 days' immersion, the bars were taken out, well washed, cleaned with chamois leather until all adherent deposits were removed, dried thoroughly, and weighed again. The bars were then re-immersed in the same jars and sea water as before, for a further period of 75 days, cleaned thoroughly again, and re-weighed.

The results obtained are given in Table IV., and are set out in graphical form in Figs. 2 and 3. The upper and lower set of curves in each case are respectively those obtained after 166 days' and 91 days' immersion.

It will be convenient to consider these results in three main groups, as indicating the influence—(a) of carbon, (b) of treatment, and (c) of time, respectively, upon the corrodibility of these steels in sea water.

(a) *Influence of Carbon.*

A comparison of Figs. 2 and 3 shows clearly that the influence exerted by increasing percentages of carbon upon the corrodibility of iron is of two distinct types, dependent upon the treatment employed.

In the *normalised, rolled, and annealed* steels, where the cooling through the critical ranges during treatment has been sufficiently slow to produce well-defined pearlite, the corrodibilities tend to rise with increase of carbon up to 0.81 per cent.

carbon, but, without exception, fall again on reaching 0.96 per cent. carbon. This points very strongly to the conclusion that the corrodibility rises to a maximum at saturation point (0.89 per cent. carbon), and begins to fall on the appearance of free cementite in the steel. Other evidence, given later, also supports this conclusion.

TABLE IV.—*Sea Water Corrosion Results.*

Treatment.	Steel No.	Carbon per Cent.	Weight before Immersion, in Grammes.	Weight after 91 Days Immersion in Grammes	Loss in Weight after 91 Days' Im- mersion, Per Cent.	Weight after 166 Days' Immersion in Grammes	Loss in Weight after 166 Days' Im- mersion, Per Cent.
Annealed (A).	1	0.10	63.8038	63.5700	0.366	63.3239	0.752
	2	0.24	64.5852	64.3112	0.424	64.0667	0.803
	3	0.30	63.8254	63.5600	0.416	63.3149	0.801
	4	0.55	63.6710	63.4004	0.425	63.1314	0.848
	5	0.81	63.5256	63.2200	0.481	62.9278	0.941
	6	0.96	63.8870	63.5926	0.461	63.3240	0.881
Normalised (N).	1	0.10	63.7760	63.5058	0.424	63.2750	0.786
	2	0.24	63.3868	63.1120	0.433	62.8724	0.812
	3	0.30	64.5350	64.2545	0.435	64.0012	0.827
	4	0.55	63.5522	63.2248	0.515	62.9330	0.974
	5	0.81	64.0190	63.6424	0.588	63.3224	1.088
	6	0.96	64.4842	64.1544	0.512	63.8125	1.042
Rolled (R).	1	0.10	64.5524	64.2950	0.399	64.0728	0.743
	2	0.24	64.3982	64.1500	0.385	63.9100	0.758
	3	0.30	64.5544	64.3122	0.375	64.0570	0.771
	4	0.55	63.6150	63.3234	0.458	63.0600	0.872
	5	0.81	64.0697	63.7442	0.508	63.4576	0.955
	6	0.96	64.2130	63.9200	0.456	63.6457	0.868
Quenched (C).	1	0.10	64.1452	63.8800	0.413	63.6534	0.771
	2	0.24	65.1968	64.84.0	0.543	64.5608	0.981
	3	0.30	65.0368	64.6895	0.534	64.3835	1.010
	4	0.55	65.2292	64.8614	0.564	64.52.2	1.088
	5	0.81	65.2700	64.8765	0.603	64.5400	1.124
	6	0.96	65.5850	65.1800	0.617	64.8552	1.119
Tempered (D).	1	0.10	64.5094	64.2920	0.337	64.0610	0.699
	2	0.24	64.5400	64.2920	0.384	64.0244	0.803
	3	0.30	65.1546	64.8440	0.477	64.5255	0.971
	4	0.55	64.6986	64.3364	0.560	64.0112	1.067
	5	0.81	65.0828	64.7130	0.568	64.3640	1.111
	6	0.96	64.8880	64.5042	0.501	64.1238	1.184
Tempered (E).	1	0.10	63.9120	63.6589	0.391	63.4299	0.754
	2	0.24	64.8710	64.6128	0.398	64.3796	0.757
	3	0.30	64.7970	64.5073	0.447	64.2745	0.806
	4	0.55	65.9828	64.7286	0.544	64.4950	0.903
	5	0.81	65.8320	65.4578	0.568	65.2200	0.930
	6	0.96	66.6814	65.7049	0.570	65.4500	0.956

The ratio of the increase of corrodibility to the carbon percentage is more satisfactorily shown in the 166 days' immersion

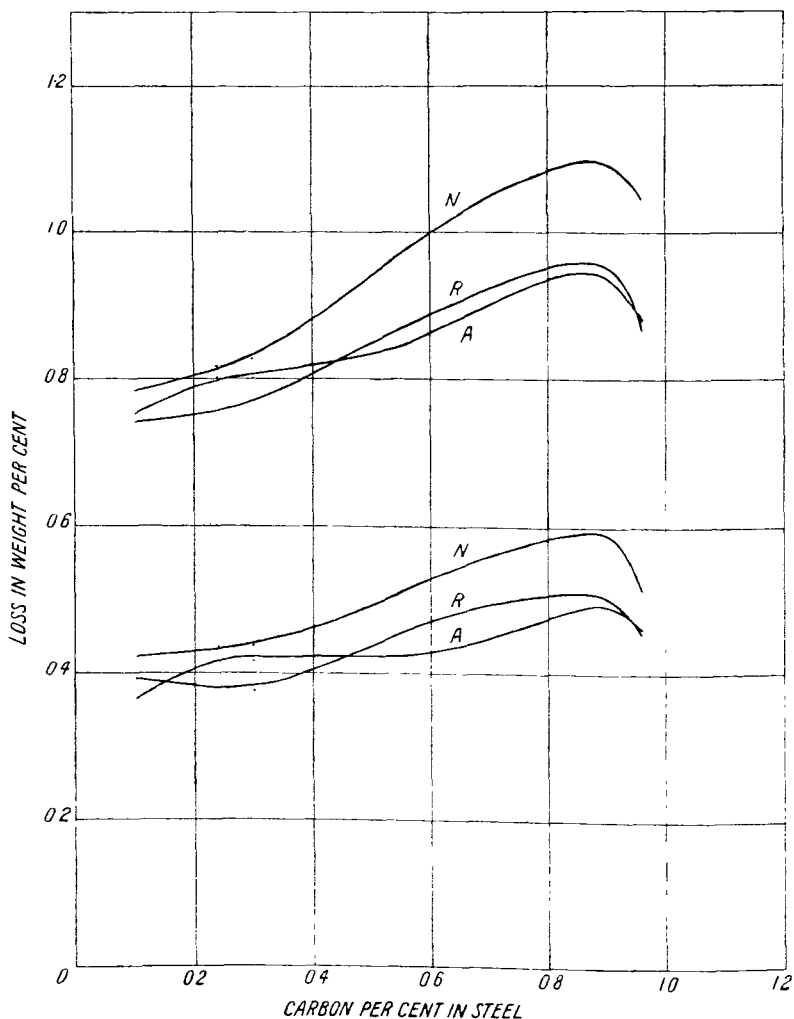


FIG. 2.—Results of Corrosion Tests on Carbon Steels.

results than in those taken over the shorter period. From the upper set of curves shown in Fig. 2, it is seen that the increase in corrodibility after 166 days' immersion is continuous with

the rise of carbon from 0.10 per cent. to 0.81 per cent. in the case of all three treatments considered.

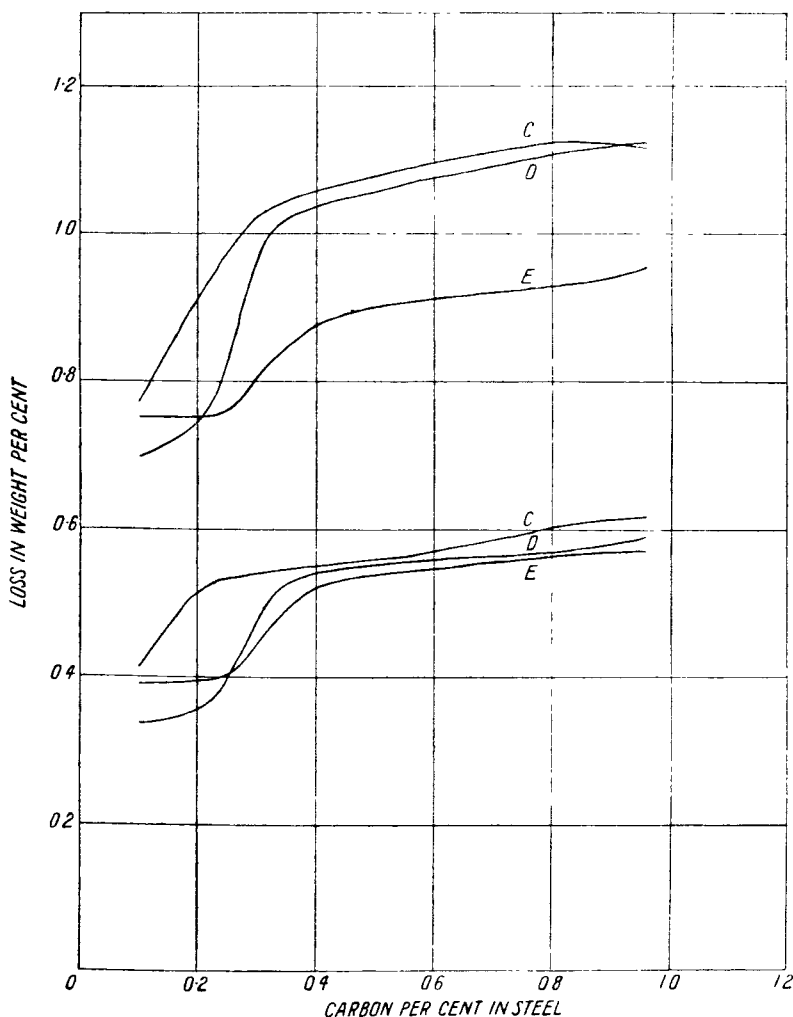


FIG. 3.—Results of Corrosion Tests on Carbon Steels.

In the normalised and rolled steels this increase is less rapid in the low-carbon range, from 0.10 per cent. to about 0.30 per cent. carbon, than in the higher range up to the saturation

point. This feature is noticeable in the 91 days', as well as in the 166 days' immersion results.

The small influence exerted by carbon in the low percentage range, probably accounts for the inconclusiveness of many of the relative corrodibility results obtained during the wrought iron versus mild steel contest. The greater quantity of slag and other impurities in the wrought iron may easily set up more than sufficient galvanic action¹ to counteract the decrease in corrodibility due to lower carbon contents.

The annealed specimens are somewhat less regular in their behaviour with rise of carbon up to the saturation point, than is the case with the rolled and normalised steels, although this irregularity diminishes with more prolonged immersion. The presence of massive cementite in Nos. 1 (A) and 2 (A), and to a slight extent in No. 3 (A), due to the Fe_3C laminae of the pearlite partially coalescing together in the process of annealing, may be largely the cause of the apparently irregular behaviour of these low-carbon annealed steels.

With regard to the decrease in corrodibility observed with rise of carbon from 0.81 per cent. to 0.96 per cent., interesting confirmation has been obtained from experiments carried out on a series of iron-carbon steels containing 3 per cent. of tungsten. These steels were kindly supplied by Mr. T. Swinden, B.Met., to whom the author wishes to express his indebtedness.

The analysis of the steels composing this series will be found in Table V., and are taken from Mr. Swinden's paper² on "Carbon-Tungsten Steels," where further information regarding their microscopic and other features may be found.

TABLE V.—*Analysis of Carbon-Tungsten Steels.*

Mark.	Carbon per Cent.	Tungsten per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Aluminium per Cent.
924	0.14	3.25	0.044	0.065	0.055	0.010	0.011
922	0.22	3.24	0.050	0.071	0.050	0.010	...
921	0.48	3.11	0.060	0.075	0.050	0.010	...
920	0.57	3.17	0.078	0.080	0.054	0.010	...
965	0.89	3.08	0.039	0.093	0.040	0.012	...
964	1.07	3.09	0.040	0.055	0.042	0.012	0.014

¹ J. W. Cobb, *Journal of the Iron and Steel Institute*, 1911, No. I. p. 170.

² *Journal of the Iron and Steel Institute*, 1907, No. I. p. 291.

The corrodibility tests were carried out under exactly the same conditions as those previously described, the only deviation being in the case of steel No. 965, where the test-bar was only $3\frac{1}{2}$ inches long instead of the standard length ($4\frac{1}{2}$ inches). The results, after 91 days' immersion, are given in Table VI.

TABLE VI.—*Sea Water Corrosion Results on Carbon-Tungsten Steels.*

Mark.	Carbon per Cent.	Tungsten per Cent.	Weight before Immersion in Grammes.	Weight after 91 Days' Immersion in Grammes.	Loss in Weight. Per Cent.
924	0.14	3.25	65.3618	65.1216	0.368
922	0.22	3.24	65.3186	65.0726	0.378
921	0.48	3.11	65.6550	65.3900	0.405
920	0.57	3.17	64.3380	64.0746	0.412
965	0.89	3.08	48.0280	47.7750	0.530
964	1.07	3.09	63.7820	63.5070	0.433

These results, which are graphically shown in Fig. 4, entirely corroborate those obtained with the iron-carbon steels. The

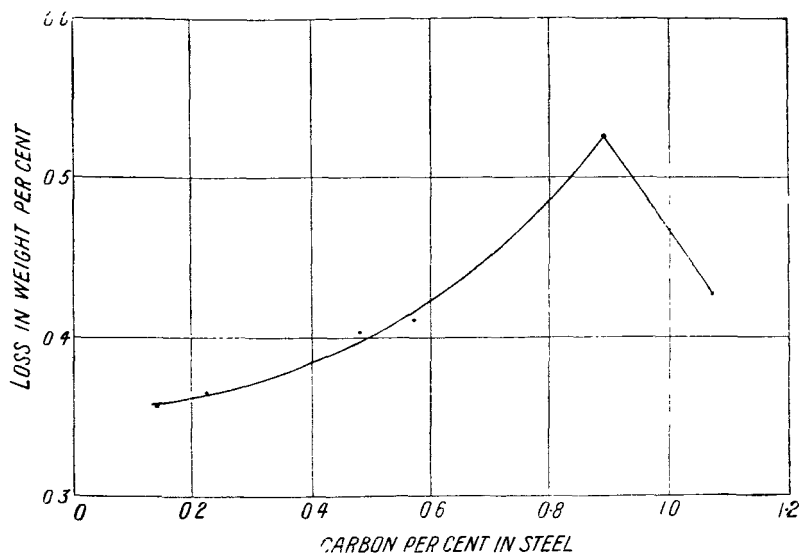


FIG. 4.—Results of Corrosion Tests on Carbon-Tungsten Steels.

corrodibility steadily rises to a maximum at 0.89 per cent. carbon, which is practically the saturation point in this series

of steels (*loc. cit.*). The appearance of free cementite again produces a marked decrease.

Comparison with the values given by the rolled steels in the iron-carbon series, shows that the influence exerted by the 3 per cent. of tungsten present in these steels is very small, and is quite insufficient to warrant any definite conclusions as to the influence of tungsten on the corrodibility of steel.

The *quenched* and *tempered* steels of the iron-carbon series show a continuous rise in corrodibility, with increase of carbon throughout the whole range investigated. No indications of a maximum corrodibility at the saturation point are found, as in the previously described instances.

The proportional increase in corrodibility is very rapid in the range from 0.10 per cent. to approximately 0.40 per cent. carbon, but beyond this point the rate of increase relative to the rise in carbon percentage becomes very small. The increase in this latter range is remarkably constant. The dissimilarity between these two ranges is probably due to incompleteness of the hardenite-ferrite solution in the low carbon steels under the conditions of quenching which were adopted.

The behaviour of these steels in the higher carbon range shows clearly that variations in carbon exert much less influence when the carbide is evenly distributed throughout the steel—either in solution or in the emulsified form—than when it is present in the more concentrated normal pearlite form.

(b) *Influence of Treatment.*

The influence of treatment is almost as important as that of carbon percentage. On the whole, annealing renders the steel most resistant to corrosion in sea water, whilst quenching causes it to corrode most rapidly. Normalising decidedly increases the corrodibility of the steels as rolled in this series. The extent to which this may prove to be a general rule must necessarily be open to modification, and possibly to exceptions, in view of the variations in these treatments in practice. The influence of tempering appears to be considerably influenced by the temperature at which the tempering is carried out. In the case of treatment D (tempered at 400° C.), the corrodibility is

but slightly less than that of the quenched steels, and generally higher than any of the pearlitic steels. On increasing the tempering temperature to 500°C , as in treatment E, the corrodibility is reduced in all except the very low carbon steels. This decreased corrodibility, with rise in tempering temperature, is comparatively slight as measured after 91 days' immersion, but after longer immersion becomes very pronounced.

The influence exerted by treatment upon corrodibility may be the result of changes produced in the physical or chemical condition of the carbide, and also in the physical condition of the steel as a whole. The information available regarding the factors involved in the corrosion of steel is not yet sufficiently detailed for absolute certainty, but it is nevertheless probable that the main factors determining the corrodibility of pearlitic steels, and which may be influenced by treatment, are as follows:—

- (a) The difference of electrical potential between the pearlite and the ferrite or cementite.
- (b) The difference of electrical potential between the Fe_3C and the ferrite in the pearlite itself.
- (c) The state of division of the Fe_3C in the pearlite.
- (d) The differences of potential existing between various parts of the steel due to variations of internal stress.

Accurate differentiation of the relative importance of these factors in determining the sum total of the influence exerted by a given treatment is obviously difficult, as the same treatment may not necessarily influence all the factors similarly, so far as their influence upon corrodibility is concerned. With a view, however, to obtaining some evidence upon this point if possible, determinations of the electro-potentials of steels Nos. 1 and 5 in all states of treatment have been made, after several weeks' immersion in sea water. The method employed in these determinations has been to combine the steel-sea water element with a calomel electrode of known constant electro-potential. The electromotive force of the combination is then measured by comparison with that of a standard cadmium cell. The comparison is carried out by a modification of Poggendorf's compensation method, a capillary electro-

meter being employed to determine the point of balance between the two electromotive forces.

The values obtained may be taken as being at any rate roughly indicative of the relative electro-potentials of the ferrite and pearlite constituents respectively, in the various states of treatment; and also, but to a less extent, of the difference of potential between the components of the pearlite itself. The results, together with the corresponding differences of potential in each case, are given in Table VII., and are arranged in the ascending order of the differences of potential.

TABLE VII.—*Electro-potentials in Sea Water, &c.*

Treatment.	Electro-potential in Volts.		Difference of Potential in Volts.	Loss in Weight per Cent. after 166 Days' Immersion in Sea Water.	
	Steel No. 5. 0·81 per Cent. Carbon.	Steel No. 1 0·10 per Cent. Carbon.		Steel No. 4. 0·55 per Cent. Carbon.	Steel No. 5. 0·81 per Cent. Carbon.
A	0·2150	0·2169	-0·0019	0·847	0·941
R	0·2129	0·2100	+0·0029	0·872	0·955
E	0·2281	0·2145	+0·0138	0·903	0·930
N	0·2234	0·2088	+0·0146	0·974	1·088
D	0·2216	0·2037	+0·0180	1·067	1·111

On comparing these differences of potential between the constituents with the corrodibility values in the corresponding states of treatment given by steel No. 4 (see Table VII.), in which steel both ferrite and pearlite are present in considerable quantities, a distinct correlation is seen to exist in the influence of treatment upon both values. This agreement is only slightly less complete in the case of steel No. 5, failing in but one instance (Table VII.).

It appears, therefore, that in unsaturated steels containing any appreciable amount of pearlite, say from 0·40 per cent. up to 0·89 per cent. carbon, the dominant forces governing their corrodibility in sea water are the two factors (*a*) and (*b*), *i.e.* the galvanic action between the pearlite and ferrite, and between the components of the pearlite itself.

These two factors are accentuated in tempered steels by the emulsified nature of the Fe_3C , which facilitates galvanic action in the pearlite: and also by the presence of residual quenching stresses, which are likely to be sources of differences of electrical potential, and consequently of galvanic action. The converse of these supplementary factors operates in the annealed steels, where the resolution of the pearlite into the laminated variety reduces the number of galvanic couples within the pearlite to a minimum. The influence of annealing in removing stresses also comes into play in reducing the liability to corrosion, although a comparison with the corrodibility values of the rolled bars shows that this influence has been very small in the case of these steels. The wide variations in steels "as rolled," however, render annealing, nevertheless, a necessary safeguard where resistance to corrosion is required.

Endeavours to ascertain, and differentiate between, the forces at work in the corrosion of quenched steels have not been productive of sufficiently clear evidence to warrant definite statements. Attention may be drawn, however, to the remarkable similarity in type which exists between the corrodibility curves of the quenched and tempered steels (Fig. 3), despite the fundamental difference produced in the condition of the carbide by the respective treatments. It might be mentioned, in this connection, that the electro-potential of steel No. 5 after quenching was 0.2040 volts. It will be seen, by comparison with the values given in Table VII. for the same steel in the tempered condition, that a very drastic change in potential is involved in the tempering of quenched steels. This is so considerable as entirely to preclude any possibility of this similarity observed between the corrodibility curves being due to any similarity in the electro-potentials of the main constituents. The evidence consequently tends, by a process of elimination, to attribute the similarity to the feature which is common to both their treatments, that is the physical influence, more or less modified, of the quenching process. On the other hand, this deduction derives little or no support from the results given by steel No. 1, where the influence of stresses is least complicated

by the presence of carbon, and which should consequently be most productive of corroborative evidence on this point.

Moreover, in the range above 0.4 per cent. carbon, in which the solution of the carbide may be presumed to have been fairly even throughout the steel, the corrodibility curves of the quenched and tempered steels are practically a linear function of the carbon contents. The concentration of the solution in carbon would therefore appear to exert some influence, but the small effect produced by variations in this concentration, militate against it being considered a very important one. This question, therefore, is one that requires further investigation.

(c) *Influence of Time.*

Comparison between the results, after 91 days' and 166 days' immersion respectively, shows that the influence of time on the rate of corrosion varies considerably with different steels over these periods. The most striking example is that of the E steels, where the ratio between the rates of increase of corrosion and of time falls on the average by nearly 10 per cent.

In order to obtain some data as to the influence of time in a specific case under the conditions of test employed, a series of six bars of steel, No. 1 (R), were immersed at the same time under standard conditions, and removed at intervals of 21 days after each other. The results are given in Table VIII., and plotted in Fig. 5.

TABLE VIII.—*Influence of Time on the Rate of Corrosion.*

Mark.	Carbon per Cent.	Length of Immersion in Days.	Weight before Immersion in Grammes.	Weight after Immersion in Grammes.	Loss in Weight per Cent.	Corrodibility Ratio.	Alternating Stress Test, Reversals.
1.0	0.10	0					236
1.1	0.10	21	65.5066	65.4455	0.093	100	208
1.2	0.10	42	66.0786	65.9617	0.177	190	234
1.3	0.10	63	66.9738	66.7950	0.267	287	234
1.4	0.10	84	66.5420	66.3000	0.364	392	224
1.5	0.10	105	66.4796	66.1767	0.456	490	232
1.6	0.10	126	65.4132	65.0519	0.553	594	228
1	0.10	166	...	...	...	...	238

In this low-carbon steel the corrodibility is practically directly proportional to the length of immersion throughout the period covered by the test.

In view of Longmuir's¹ interesting experiments on the mechanical deterioration of steels resulting from corrosion, the bars employed in this "influence of time" series were

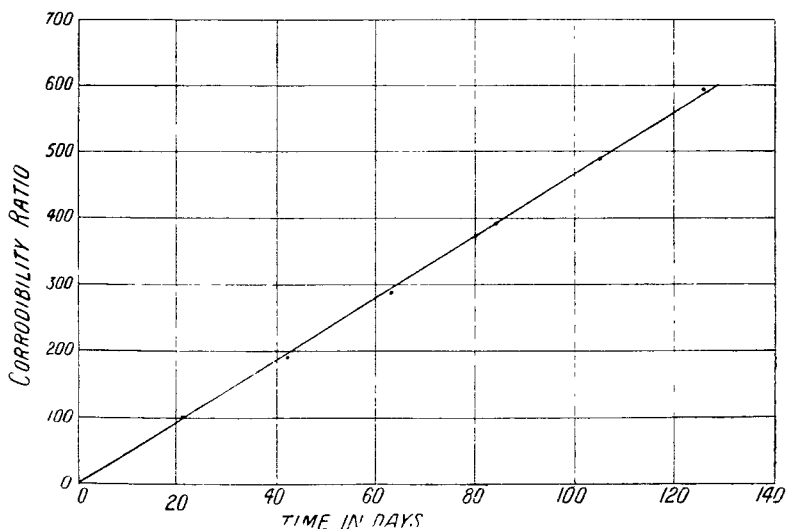


FIG. 5.—Influence of Time on Rate of Corrosion.

tested after immersion on Dr. Arnold's alternating stress testing machine. The usual standard conditions of test were employed. Similar tests were also carried out on the same steel before corrosion, and after 166 days' immersion. The results, which are included in Table VIII., show that no appreciable change has been produced in the mechanical properties of the steel within five months' immersion in sea water.

Notes on the Nature of the Deposits on the Bars.

The deposits in general consisted, in the first place, of a complete outer layer of a light brown colour, which was flocculent in nature. This was easily removed on washing.

¹ *Journal of the Iron and Steel Institute*, 1911, No. I. p. 147.

and constitutes the usual "rust." Underlying this was invariably found a layer of darker brown colour, which was less flocculent and more adherent, but could usually be removed with comparative ease. Beneath this, on the surface of the bar itself, was found a thin layer of a very dark bluish-black colour. This was usually found in two forms. Sometimes it was very loosely adherent, and washed off fairly easily with rubbing, together with the dark brown layer mentioned above. The quenched and tempered steels were usually evenly and completely covered by a layer of this form, but the steels in the other states of treatment were only partially covered by this deposit. The other form, which was found in the majority of the steels, and usually in addition to the previous one, was mainly concentrated at the lower end of the bar, where it was very firmly adherent and involved considerable difficulty in its removal. This bluish-black deposit tends to increase with a rise in the carbon percentage, so that it is probably largely composed of the carbide residue resulting from the disintegration of the surface of the bar, mixed with the ferrous hydroxide, which forms the first stage in the passage of the iron into the ultimate Fe_2O_3 or ferric state of oxidation.

Notes on the Surfaces of the Corroded Bars.

The normalised, rolled, and annealed bars invariably showed a crystalline appearance on examination after the removal of the deposits. These markings were especially pronounced in the annealed steels, and tended to become finer with rise of carbon.

This type of surface was also found in the quenched and tempered steels in the case of steel No. 1, and to a slight extent in steels Nos. 2 and 3; but in the higher carbon steels the surface shows an even, amorphous appearance, with few or no signs of crystallinity occurring. This supports the explanation previously advanced, accounting for the irregularity of the corrodibility results given by the low-carbon quenched, and tempered steels, on the score of the incompleteness of the hardenite-ferrite solution in these steels under the conditions of quenching.

MICROSCOPIC ANALYSIS.

The microscopic features correspond quite normally to the structures demanded in pure iron-carbon steels by the respective carbon contents of the series. These have been previously described by Arnold¹ and others, so that detailed description may therefore be dispensed with. The main feature is the strong tendency to lamination in the pearlite, which is not only found in the annealed steels, but to a considerable extent in the rolled steels also. The pearlite in the normalised steels is mainly of the diffused variety. In the unquenched specimens of the 0.96 per cent. carbon steel the free cementite is found as specks evenly distributed over the field.

MICROSCOPIC EXAMINATION AFTER CORROSION.

This section of the work has been confined to the normalised, rolled, and annealed steels. The ordinary microsections used for the microscopic analysis were employed, and were taken from the treated bars before turning down to finished size. The edges of each microsection were coated with paraffin wax to prevent any mill scale exerting galvanic action on the surface which was being examined. The sections were polished exactly as for the usual microscopic examination, and then subjected to progressively longer immersions in sea water. They were then examined under the microscope, after the removal of the oxides by vigorous rubbing on selyt cloth.

(a) *Steels Nos. 1, 2, and 3. Mild Steels.*

These steels are taken together because structural steels are usually found within this carbon range, and it is in connection with this class of steels that the question of corrosion becomes most important.

The first feature in the process of corrosion is the appearance of numerous dark spots due to the action of the manganese sulphide. After about two hours' immersion the corrosion of the pearlite areas becomes faintly visible. This

¹ *Minutes of Proceedings of the Institution of Civil Engineers*, 1896, vol. cxviii.

pearlite action rapidly increases in vigour, and begins to extend its influence to the immediately adjacent ferrite. The attack next develops at the boundaries of the ferrite crystals, and after forty-eight hours' immersion this feature becomes very marked (Plate XXXIII. Fig. 4). So far as can be seen, this action along the ferrite boundaries is different from the production of boundary lines by ordinary etching effects, and suggests distinct penetration along these ferrite junctions. This may account to some extent, at any rate, for the well-known deteriorating influence exerted by prolonged corrosion upon the mechanical properties of mild steel. With further progress of time, selective corrosion of various ferrite crystals sets in, some crystals corroding with comparative rapidity, whilst others remain quite untouched. This selective action is quite irrespective of the influence of the pearlite areas, and can be seen commencing even after forty-eight hours' immersion (Plate XXXIII. Fig. 4). Pitting also becomes pronounced in the ferrite after four or five days, especially in the regions surrounding the pearlite areas. This action, together with the corrosion of the pearlite and adjoining areas, and the selective attack in the ferrite portions, continues, until, after twenty-one days' immersion, two distinct types of field begin to develop. The main portion consists of a dark corroded background, containing the pearlite areas and some of the ferrite. Under the microscope this background is confused and generally indistinct in its features, with the exception of a crystalline structure which is sometimes evident under the low-power magnification. An example of this is seen in part of Plate XXXIV. Fig. 1. The remainder of the field, varying from about 30 per cent. of the whole in the case of the 0.10 per cent. carbon steel, to approximately 10 per cent. in that of the 0.30 per cent. carbon steel, consists of fairly bright and comparatively unattacked ferrite areas. The pits previously mentioned are much more distinct and numerous, and show distinct signs of geometrical form. Three, four, and five-sided figures, suggestive of the various sections of the cube, are seen distributed over these ferrite areas, and can also be observed, although with greater difficulty, in the ferrite portions of the corroded background.



FIG. 1.—Steel No. 1 (N) after 20 weeks' corrosion in sea water, showing rectangular pits. Magnified 200 diameters and reduced.



FIG. 2.—Steel No. 1 (N) after 20 weeks' corrosion in sea water, showing rectangular pits. Magnified 200 diameters and reduced.



FIG. 3.—Steel No. 1 (N) after 20 weeks' corrosion in sea water, showing non-rectangular pits. Magnified 250 diameters and reduced.



FIG. 4.—Steel No. 2 (A) after 48 hours' corrosion in sea water, showing early stages of attack. Magnified 200 diameters and reduced.



FIG. 5.—Steel No. 5 (N) after 20 weeks' corrosion in sea water, showing pits due to manganese sulphide. Magnified 250 diameters and reduced.

PLATE XXXIV



FIG. 1.—Steel No. 2 (A) after 3 weeks' corrosion in sea water, showing decarbonised edge. Magnified 75 diameters and reduced.



FIG. 2.—Low-carbon steel after 3 weeks' immersion in sea water, showing effect of roaks. Magnified 200 diameters and reduced.



FIG. 3.—Low-carbon steel after 3 weeks' corrosion in sea water, showing effect of roak in the interior of the steel. Magnified 200 diameters and reduced.



FIG. 4.—Steel No. 1 (A) after 3 weeks' corrosion in sea water, showing the effect of mill scale action. Magnified 180 diameters and reduced.

The sections were then examined, after twenty weeks' immersion, so as to obtain information regarding the structure, after a period of time comparable in length to those employed in the corrodibility determinations. The main background, consisting of the most deeply corroded portions, cannot be resolved under the microscope, except in some areas where the pits in the ferrite show up more clearly by reason of their sharp geometrical form. The bright ferrite areas remain, but in smaller proportion than before, varying from 20 per cent. to 5 per cent. of the whole, with rise of carbon from 0.1 per cent. to 0.3 per cent. respectively. The proportion of these bright ferrite areas is larger in the annealed than in the normalised steels. Careful examination further revealed the fact that the surface of these bright ferrite areas was at exactly the same level as the original surface of the specimen, as represented by a few areas which had been preserved from attack by a covering of wax accidentally received whilst coating the sides. This identity of level was conclusively proved by the two areas both being in perfect focus at 400 diameters magnification, with the same adjustment of the objective lens. Thus, in very mild steels, an appreciable proportion of the ferrite may remain completely uncorroded even after very prolonged immersion in sea water.

Intermediate in depth, between the bright ferrite and the deeply corroded background, are also found occasional areas of partially corroded ferrite, in which the process of attack has not proceeded so vigorously as in those areas found in the background.

The pits in the ferrite constitute a most striking feature, on account of the extremely sharp development of their geometrical form as a result of the prolonged immersion. On detailed examination being made of the shape of these pits, it was found that those in the bright ferrite areas were almost exclusively rectangular, and principally square (Plate XXXIII. Figs. 1 and 2). Indeed, the total number of non-rectangular pits was not usually more than ten or fifteen in the whole of the bright ferrite areas, whereas a similar number of rectangular pits could often be found in a single one of these areas, as shown in the photomicrographs. These non-rectangular pits were not

usually complete, but an exceptionally well-developed and rare example is shown in Plate XXXIII. Fig. 3.

The pits in the partially attacked ferrite, which has been previously described, were found to contain a very much larger proportion of non-rectangular sections than was found in the unattacked ferrite areas: whilst the pits in the deeply corroded ferrite in the background, showed a considerable preponderance of the non-rectangular sections, so far as they could be clearly seen under the microscope.

The pits in any particular ferrite crystal were invariably identical in shape, and in the directions of their main axes. They are evidently controlled, therefore, by the internal structure of the crystal itself, so that differences in the shape of the pits in respective crystals may be taken as indicative of differences in the relationship existing between the surface exposed to attack and the axes of those ferrite crystals.

In view of the previously described variation in the general shape of the pits, with increase in corrodibility, it follows that the relationship between the crystallographic axes of a ferrite crystal, and the particular surface of it which is exposed to attack, is *ceteris paribus* an important factor in determining its rate of corrosion. This is quite in accordance with previous knowledge regarding the variation of the solution pressure of crystal faces, with their relation to the crystallographic axes, but its practical importance as a factor in the corrosion of iron and mild steels has not previously been recognised.

This factor has an important bearing on the corrosion of steel castings, where the crystals on the exterior tend to grow perpendicular to the surface during solidification. The relation of the exposed surface to the axes of the respective crystals is practically the same in every case, so that differences of potential due to this factor will be at a minimum, and the resistance of the surface to corrosion will be proportionately greater in consequence. Other reasons have been advanced, in the past, to account for the generally observed resistance of castings to corrosion, and are probably to some extent correct, but this additional phase of the question is one which must also be kept in mind.

Concerning the much debated question of the corrosion of

pure iron, it may also be remarked that it is difficult to see how even the purest iron, in the ordinary form, could be prevented from passing into solution when immersed in a conducting liquid. Differences of potential between the ferrite crystals themselves are inevitable, in view of the unavoidable variations in their respective orientations, so that all the elements of galvanic action would consequently exist. The author would venture to suggest this new factor as an addition to Dr. Friend's already lengthy list of the "various factors influencing the rate of corrosion of relatively pure iron."¹

(b) *Steels Nos. 4, 5, and 6.*

The large proportion of pearlite in these steels causes corrosion to take place rapidly. After one or two weeks' immersion, it is practically impossible to distinguish any clear features in the larger portion of the section by means of the microscope. After twenty weeks' immersion the general field is confused and indistinct, showing the round pits due to manganese sulphide (Plate XXXIII. Fig. 5). Steel No. 4 shows ferrite areas containing geometrically shaped pits, but only in the case of the annealed steel are any of these ferrite areas bright and outstanding. In the annealed specimens of steels Nos. 5 and 6, mainly in the latter, a similar effect is also observed in the pearlite, where occasional areas are found distinctly raised above the general background.

The *effect of decarburisation* was markedly shown in the microscopic investigations. The decarburised edge of annealed steels (Plate XXXIV. Fig. 1) was invariably much less corroded than the remainder of the specimen, and usually remained comparatively bright. A specimen of a low-carbon steel containing roaks also showed the same effect after corrosion in sea water, the fringe of the roak being but little attacked. Two examples are shown (Plate XXXIV. Figs. 2 and 3). The decarburised surface of annealed steels would appear, therefore, to be of considerable value in protecting the steel from corrosion.

The *action of oxides* in the corrosion of steel affords peculiar

¹ *Carnegie Scholarship Memoirs*, 1911, vol. iii. p. 2.

microscopic features. Several microsections, with some mill scale still on the edges, were immersed without any wax coating on the sides. The resulting effect upon the surface adjoining the mill scale was the production of a large number of roughly circular pits, which extended some distance away from the mill scale itself (Plate XXXIV. Fig. 4). The presence of the bluish-black deposit, which has been previously described, produces identically the same effect.

SOLUBILITY.

The solubilities of all the steels have been determined in several acids, and also their electro-potentials after forty-eight hours' immersion. Further investigation into the factors involved in the solution of steel in acids is intended before any detailed communication on the influence of carbon and of treatment on solubility is made. It may be stated, however, that the absence of correlation between the corrodibilities of the steels and their solubilities in 1 per cent. sulphuric acid solution is very marked. The so-called acceleration tests, in which the relative solubilities of steels in 1 per cent. sulphuric acid solution are taken as indicative of their relative corrodibilities in neutral solutions, are entirely misleading and unreliable.

SUMMARY.

1. *Influence of Carbon on Corrodibility.*—(a) In rolled, normalised, and annealed steels the corrodibility rises with carbon contents to a maximum at saturation point (0.89 per cent. carbon), and falls with further increase of carbon beyond this point. (b) In quenched and tempered steels a continuous rise in corrodibility occurs, with increase of carbon within the range investigated (up to 0.96 per cent. carbon), no maximum corrodibility at saturation point being found in these steels.

2. *Influence of Treatment on Corrodibility.*—Quenching increases the corrodibility to a maximum; annealing tends to reduce it to a minimum; whilst normalising gives intermediate values. Tempering reduces the corrodibility of

quenched steels, but the extent of its influence varies considerably with the tempering temperature.

3. *Factors determining Corrodibility.*—The electromotive forces between the pearlite and ferrite, and between the components of the pearlite itself, are the principal factors determining the corrodibility of unsaturated pearlitic steels above 0·4 per cent. carbon. In mild structural steels, this galvanic action, due to differences of potential between the constituents, is accompanied by galvanic action between the ferrite crystals themselves. These differences of electro-potential between the ferrite crystals are the result of differences in their orientation. The state of division of the pearlite, and the presence of internal stresses in the steel, may also exert a considerable modifying influence on the foregoing factors.

4. The influence of time on the rate of corrosion varies with different steels. In a low-carbon steel it is shown to be practically directly proportional to the length of immersion.

5. The influence of corrosion on the resistance offered by a low-carbon steel to alternating stress is not appreciable within a period of five months' immersion.

6. Three per cent. of tungsten produces practically no change in the corrodibility of carbon steels.

7. Decarburisation increases the resistance to corrosion.

8. The two oxides, FeO and Fe_3O_4 (mill scale), both exert a microscopical pitting effect on steel when in contact with it in sea water.

In conclusion, the author would state that the work recorded in this paper has been carried out under the auspices of the Research Committee appointed by the British Association to investigate the influence of elements on the corrodibility of iron. The author wishes to express his indebtedness to the other members of the committee—Professor J. O. Arnold (chairman), Professor W. P. Wynne, Professor A. McWilliam, and Mr. F. Hodson, for facilities and assistance afforded in the carrying out of the work, and to Dr. W. E. S. Turner (secretary), whose kindly counsel and help in many difficulties call for an especial tribute of gratitude. The author's best thanks are also due to Mr. J. H. Harrison, for the great care shown in the preparation and treatment of the test-pieces.

DISCUSSION.

Professor T. TURNER (Birmingham) said it was an interesting fact that an increase of carbon up to a certain extent increased the corrosion of steel by diluted acids, but that as the carbon was further increased and cementite began to separate the corrosion decreased. If they would proceed a little further on that line of inquiry they naturally came to cast iron, and it was well known that white cast iron was resistant to acids. Experiments were made in his laboratory last year by Dr. Gwyer with some samples of cast iron which had been exposed to the slow action of acetic acid. It was observed that grey cast iron exposed to the action of dilute acid lost its ferrite first; the phosphorus eutectic and any cementite was left behind, and of course the graphite. It was a very curious fact that the action of alkalies was different. If they took a sample of grey cast iron containing phosphorus eutectic and some carbide and heated it with caustic soda or potash, it would be found that the phosphorus eutectic and iron carbide were dissolved out first, and the ferrite was left. It was an extremely interesting experiment to prepare two separate slides from similar iron, one exposed to alkalies and one exposed to acids. In one case the free iron all went, and in the other case the iron was left. In connection with all those corrodibility experiments they must consider not only the kind of metal employed, but also the kind of acid, the strength of the acid, and further, the effect of substances other than acids. When salts or other substances came into contact with iron, they would lead to corrosion on one hand, or they might offer a certain amount of protection on the other.

CORRESPONDENCE.

Mr. JOHN W. COBB (Leeds) wrote that having worked on the subject of the influence of impurities on the corrosion of iron, he was specially interested in Mr. Chappell's valuable paper, which he hoped was only the beginning of a systematic survey of the influence of specific impurities. How closely corrosion was bound up with electrochemical action between pure iron and those accompanying substances which converted it into a material of construction bearing the same name but different in nature, was perhaps never better illustrated than by the correspondence between the author's experimental results from corrosion tests and the simple theoretical deduction previously published in his (Mr. Cobb's paper), which read: "If other conditions could be made exactly the same, the iron dissolved on etching two irons containing no impurity but carbon would be in the order of the amounts of the pearlite (eutectic) present. The all-pearlite iron containing 0.9 per cent. carbon would show the

greatest rate of dissolution; any excess of iron or carbon would lessen it."¹ The agreement was closer than he would have expected for any but carefully normalised metal. The realisation that iron or steel was not a chemical entity but a complex substance, containing within itself, in varying degrees, the potentialities of its destruction under normal conditions of exposure, was bringing into desirable prominence the study of the metal itself in the corrosion process. It had been taken for granted too frequently that a very interesting problem of pure chemistry, the mode of initial combination of the chemical element iron with oxygen, water, and carbonic acid, was the only vital problem of corrosion.

In connection with Professor Turner's opening remark, Mr. CHAPPELL desired to point out that the maximum corrodibility at 0.9 per cent. carbon, described in the paper, did not refer to dilute acid, but strictly to sea-water attack only, *i.e.* a practically neutral solution. The need for scrupulous care in corrosion work in avoiding any confusion between different types of solutions, such as those, could not be more effectively exemplified than by the very interesting experiment which Professor Turner himself subsequently described.

The close corroboration of theory by experiment in the case of the maximum corrodibility at 0.9 per cent. carbon, as mentioned by Mr. Cobb, was particularly interesting. Reference to the context of Mr. Cobb's quotation, however, indicated the attacking medium under consideration to have been of an acid rather than of a neutral nature. In view of that, the author questioned the accuracy of the earlier deduction that the corrodibility "would be in the order of the amounts of the pearlite present," in the case of dilute acid solutions. The proportionality of the corrodibility to the pearlite contents was obviously only likely to obtain so long as the electro-chemical action between the constituents was the dominant factor governing the corrosion. It had previously been tentatively suggested¹ that in mineral acid solutions even so dilute as 1 per cent., the difference in potential between the constituents was no longer the dominant factor in the process of attack, but was probably quite secondary to the influence of the actual electro-potential of the steel itself; that latter factor, on the other hand, being quite a negligible one when the corroding solution was neutral. Experimental data obtained on the carbon steels used in the present research had tended strongly to support that conclusion, as would be seen from a typical comparative study of some of those results given in the following Table A. That drastic change in the nature of the factors involved when a practically neutral salt solution was replaced by an even highly dilute acid one, called for a sharp differentiation between corrodibility and solubility. It also added emphasis to the previous appeal

¹ *Journal of the Iron and Steel Institute*, 1911, No. 1, p. 170.

¹ Chappell and Hodson, *British Association Report*, 1910, p. 566.

TABLE A.

Solution.	Treatment.	Approximate Difference of Electro-potential in Volts between Pearlite and Ferrite (Steels Nos. 5 and 1).	Steel No. 4 (0.55 per Cent Carbon).		
			Electro-potential in Volts. ¹	Corrodibility, 166 Days' Immersion.	Solubility, 48 Hours' Immersion.
Sea water	A	-0.0019	0.2129	0.847	
	R	+0.0029	0.2200	0.872	
	E	+0.0138	0.2252	0.903	
	N	+0.0146	0.2091	0.974	
	D	+0.0180	0.2090	1.067	
One per Cent. Sulphuric Acid Solution.	D	+0.0076	0.0013		1.15
	N	-0.0117	0.0032		1.32
	R	-0.0051	0.0081		1.35
	E	+0.0121	0.0010		1.41
	A	+0.0013	0.0146		1.71

for rigid attention to apparently slight details of that kind if confusion were to be avoided in the promising and rapidly developing subject of corrosion research. Attention might also be called to the practically complete reversal of the influence of treatment on the corrodibility and solubility respectively, as corroborative of the absence of any substantial correlation between the action of neutral and very dilute acid solutions.

Despite those facts, however, it might be mentioned that experimental data obtained as to the solubility in 1 per cent. sulphuric or hydrochloric acid solutions of several series of steels containing carbon as the only variable, indicated that although the solubility was not proportional to the pearlite contents, yet the maximum solubility did occur at about 0.9 per cent. carbon. The position of that maximum was exceedingly sensitive to even slight variations in the other elements present, notably manganese.

The author most heartily endorsed Mr. Cobb's remarks as to the need for increased concentration on the metal itself, as the central factor in the corrosion problem. In view of that gentleman's encouraging appreciation it might be added that the extension of the present work, by similar systematic studies of the influence of other elements on corrosion, was the original intention, and it was hoped that subsequent circumstances might permit of their completion in due course.

¹ After three weeks' immersion in sea water; or twenty-four hours' immersion in 1 per cent. H_2SO_4 solution respectively.

MANUFACTURE AND TREATMENT OF STEEL FOR GUNS.

BY GENERAL L. CUBILLO (VALLADOLID, SPAIN).

INTRODUCTORY.

It is about thirty years since steel was definitely adopted by the chief countries of the world for gun construction. The many difficulties presented in the manufacture of large homogeneous masses of steel, and the resistance offered by tradition and routine to every change in industrial processes were the chief causes of the continuation of the use of cast and wrought iron, in the third quarter of the last century, if not for the whole construction, at least for the principal elements of guns. The celebrated American artillerist, Rodman, cast large calibre guns, of cast iron exclusively, and applied, during and after the casting process, his invention of cooling the inside of the gun with water, and of heating the outside in such a manner that the inside was compressed by the outside. By this the maximum tangential resistance of a single tube is attained, and it is then best fitted to oppose the pressure of the powder. The metal used by Rodman in the manufacture of guns was of a quality which has not since been surpassed. The pig iron employed was charcoal and cold-blast iron, from ores of the greatest purity, so that the resulting cast iron possessed the best mechanical qualities. The resistance of cast-iron guns was certainly increased by the Rodman process, though it was not known exactly by how much, since it is impossible to apply the rules of shrinkage to guns treated as described. But the improvement so obtained was not sufficient for the requirements of the artillery, and cast iron whether alone or combined with wrought iron or puddled steel, was incapable of withstanding very great pressure. It was certainly possible to fire the guns so constructed with charges larger than those employed in ordinary cast-iron guns, but

the difference was not great, since a very considerable part of the gun was made of cast iron, the mechanical properties of which are deficient as compared with those of wrought iron and steel. In France and Spain a combination of steel, wrought iron, and cast iron was tried, the former metal being employed for that part of the bore where the pressure is greatest, but this combination, which actually produced guns more powerful than those made of cast and wrought iron, was abandoned since, owing to the progress of metallurgical science, the manufacture of steel in large masses had now become possible. The guns made of this triple combination were capable of withstanding a pressure of 2200 kilogrammes per square centimetre. It was necessary to use quick-burning powders in them, because, the steel tube not being of the total length of the bore, the gun at the cast-iron end was much weaker and incapable of withstanding great pressure. It is therefore easy to understand why, as soon as it became possible to cast great masses of steel, this metal, with its greatly superior physical and mechanical properties, was exclusively adopted for the construction of large guns. It will always be a distinction, however, for the Krupp works to have been the first to cast great masses of steel, while the Bessemer and open-hearth processes were still unknown to the metallurgists, but the method by which Alfred Krupp achieved his wonderful results is so well known that it need hardly be described here.

SECTION I.

CONDITIONS OF THE STEEL REQUIRED FOR GUN CONSTRUCTION.

If it were possible to produce a metal at low cost such that it possessed a high elastic limit, and also high tenacity, great ductility, and resistance to the wear produced by the powder gases at great pressure and high temperature, with, moreover, a very high melting point, such a material would undoubtedly be the most suitable for the manufacture of guns. The very great pressure which the material must withstand is not, it is true, of great duration or of great frequency in

large and medium-sized guns ; but it is necessary to take into consideration the fact that what causes this enormous pressure is the highly heated gases, which exercise both a physical and, in a certain portion of the bore of the gun, a chemical action on the metal. As has already been said, steel has been adopted as the only material suitable for guns. But steel offers so great a variety of types, that it becomes necessary to select from among these one which possesses in the highest degree the conditions already laid down. If the steel is ordinary carbon steel, its high elastic limit is accompanied by a high tenacity and less ductility than that which accompanies a metal of smaller elastic limit and tenacity. The resistance of the former metal to dynamic stresses will be less than that of the second, and its melting point will also be lower. The gun-makers have universally adopted a metal between the dead-soft and the hard steels, namely, an iron-carbon alloy, tending rather towards mildness, due specially to its high melting point. This last property is now very important, on account of the use of the modern smokeless powders, and especially the nitro-glycerine powders. The high combustion temperature of these powders, and the incomplete obturation of the driving band of the projectile at the commencement of its travel in the bore of the gun, is the origin of what is called erosion in the bore. The modern experiments of Vieille and some others made at South Bethlehem, not to mention the earlier ones made by Sir Andrew Noble, have demonstrated without doubt that the mild steels are better able to withstand the effects of erosion, because, amongst other properties, they possess melting points higher than those of the hard steels.

An ordinary carbon steel for guns has about 0·5 per cent. of carbon, and its place in the iron-carbon solution is in the series of the metals called steels, having a carbon percentage of less than 2 per cent. The characteristic of this series is that it is not eutectic at its freezing point, and that it presents a similar phenomenon in the subsequent cooling, when it arrives at the point *Ar* in the cooling curve. All this refers only to the ordinary carbon steel. The ternary alloy of iron-carbon and nickel or the quaternary alloy of iron with

carbon, chromium, and nickel is employed in the manufacture of medium and small guns only, because the cost of such an alloy would be prohibitive in the construction of the larger ones, especially now that the principle of uniformity of calibre has been adopted by all the navies of the world. It must be said, however, that the A and B tubes for the great 16-inch experimental gun manufactured in the United States are of nickel steel. In adopting this alloy for the construction of guns it has been necessary to diminish the percentage of carbon, because if it reached that of ordinary carbon steel with percentages of 2·5 to 3·5 per cent. of nickel the steel would be very hard, that is, it would be what Mr. Guillet calls "martensitic steel."

Mechanical Tests.—It is not necessary to give here a complete table of the specifications for gun steel as required by the armies and navies of the European and American powers. In all the specifications two different kinds of mechanical tests are required: in the one case, that of continuous and progressive tension up to the yield point, together with the measurement of the elongation after breaking; while the other test consists in subjecting the test-piece to a certain number of impacts according to details and conditions fully specified, or perhaps to some bending test, equally fully specified. If the steel has been manufactured from pure materials, such as the best Swedish pig iron and from scrap from the puddling of the best hæmatite pig iron, and if it has been carefully cast, forged, annealed, hardened, and tempered, the tensile tests are quite sufficient in the author's opinion; while the close examination of the forgings during machining will, conjointly with the tensile tests, also convey a good idea of the quality of the metal, so that the impact or bending tests can be dispensed with. But perhaps it may happen that the heat-treatment has not been properly conducted, and that the metal which withstands the tensile tests may fail in the impact tests. The latter are those which give a really good idea of the brittleness of the metal. Many years ago these mechanical and bending tests were introduced into the specifications for ascertaining the presence of phosphorus in the steel. It is possible that a metal with a high percentage of this metalloid

may give satisfactory results in the static tensile tests, and that the yield point and the ductility may be very good; but this steel would certainly withstand far fewer impacts than a very pure steel. Indeed the tests, which a metal suitable for gun construction must undergo, must produce stresses similar to those caused in the gun by the powder gases. This metal, when the gun is composed of a single tube, as is generally the case in mountain guns, passes, in an infinitesimal space of time, from the state of repose to a strain of two-thirds at least of its elastic limit of static tension; and when the gun is a composite tube the concentric layers of some of its elements pass in an equally short space of time from a state of compressive stress to another of tensile stress, both of which are opposite states of stress of considerable importance. Taking into consideration both the opposite stresses to which the elements of the guns are subjected, before and under fire, perhaps the best mechanical test for gun steel would be that of alternating stresses with considerable variation, these stresses being repeated a certain number of times in harmony with the rounds fired by the guns. The shock tests are now universally accepted, as has been said, in order to ascertain the fragility of the metal. The resolutions of the last Congress of "*Les Methodes d'Essai des Materials*" assembled at Copenhagen recommend a shock test with test-pieces, together with a slight nick in one of the long sides of the piece. Certainly this test must be adopted as one of the means of ascertaining the good quality of gun steel.

SECTION II.

MELTING OF THE STEEL.

Of all the processes employed in the melting of steel the only ones used in the manufacture of gun steel have been the crucible and the open-hearth processes. The first process was naturally employed before the introduction of the open-hearth method, and for some time afterwards; but the latter has now superseded the crucible process, except at the Krupp works.

Mention has already been made of the great claims possessed by this firm as the pioneers in casting, by the crucible process, great masses of steel intended for gun construction. Credit must also be extended to the English firms of Firth, Vickers, and Whitworth, which also employed their energies in the improvement of this manufacture. The firm of Krupp has always claimed that the crucible process offers the best guarantee for a sound metal for gun construction. Undoubtedly it is possible to obtain by it a metal of great purity with regard to phosphorus and sulphur than by any other process, if the material charged in the crucibles is wrought iron from hæmatite pig iron. The metal obtained in this case will be the best possible steel and it will not contain occluded gases; or at all events in very small proportion. If the metal charged in the crucibles is free from oxides, the only gases dissolved in the steel will be those which have passed through the walls of the crucibles.

In the author's opinion steel made by the crucible process must lack homogeneity, because it is almost impossible that the composition of the charge of all the crucibles will be the same. It is also impossible to secure uniformity of composition in the ingot mould, bearing in mind segregation. The only way of securing homogeneity by this process would be to teem the crucibles first into a hot ladle, and then into the ingot mould. The principal reason for this lack of homogeneity lies in the impossibility of analysing all the puddled bars which form the charge of the crucibles, classification by the eye being very uncertain. Therefore, in the author's opinion, a massive ingot of steel cast by the crucible process is more heterogeneous than a similar ingot cast by the open-hearth process. The open-hearth acid process is generally employed for the casting of great masses of steel. The basic process can of course be employed, provided the materials charged are acid; and there is no difficulty in obtaining by the open-hearth process, that is, by the dissolution in a cast-iron bath of a certain quantity of wrought iron or steel, a very pure metal, such as is required in the construction of guns. All depends on the purity of the pig iron and scrap charged.

It is the constant practice of all the steelworks where steel

for gun construction is regularly made to employ Swedish pig iron of the best quality, the phosphorus being as low as 0.025 per cent., and the sulphur lower than this amount; and for the scrap, puddled balls or bars from the best hæmatite pig irons.

By puddling this pig it is possible to obtain a product with phosphorus and sulphur as low as 0.001 per cent., and as furnaces of 50 or 60 tons capacity are now very common, and as for the casting of the largest element of the new great guns it is not necessary to have ingots of more than 100 or 120 tons, the result is that it is not very difficult to obtain a great uniformity of the metal by this process. The conditions of open-hearth working permit of working two or three furnaces so uniformly that, at the time of casting, the metal of the two or three furnaces will be perfectly similar. The steel is much exposed to the oxidation of the furnace gases, always in contact with the bath; and to this action is added that of the iron ore incorporated for oxidising in a rapid and energetic manner the silicon and carbon in excess of that required in the steel. There are many means of diminishing the oxidation of the bath; one of them is to prepare the charge by putting in the furnace the greatest possible amount of scrap, with the smallest quantity of carbon, and conducting the refining process by the furnace gases only without the addition of any iron ore. This particular method of working is extraordinarily slow; first, because, as the materials, both pig iron and slag, are charged at once and cold, the mixed bath is very low in carbon and its melting point very high. It therefore requires more time for melting it than if the charge had been composed of equal parts of pig iron and scrap. Secondly, because the oxidation of the carbon by the gases is not so efficacious as that by the iron ore, this being more in contact with the bath and the former acting only on the surface. Operating in this way the final steel is almost free of oxides, and in order entirely to eliminate them additions are made, at the end, of certain iron alloys, such as ferro-manganese and ferro-silicon, which by their action upon the bath reduce the iron oxides dissolved in it. This addition is the more required when the charge has been of equal parts of pig iron and scrap. The

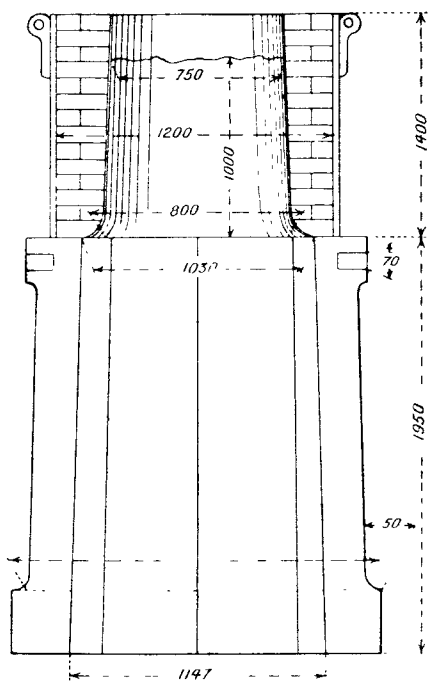
percentage of carbon of such a charge at the fusion or melting time will be very high, and it is not possible to oxidise the excess carbon to the point required in the artillery steel by the action of the gases only, and it is almost imperative to employ the iron ore for accelerating the oxidation of the carbon.

Fusion at Trubia of the ordinary Carbon Steel for Guns.—The steelworks at Trubia comprise two furnaces—one of large capacity, capable of taking charges up to 54 tons, and the other of 16 tons. Therefore it is possible, working with the two furnaces, to obtain an ingot of 64 tons. The furnaces were supplied by Messrs. Frederick Siemens of London, and are of the usual design. They are situated in a straight line, with a very commodious working platform, and are served by an electric-charging crane, of the well-known Wellman type.

For the service of the casting shop there are two overhead electric travelling cranes, one of 75 tons capacity, with one motor only of 30 horse-power, and the other is a Niles 50-ton capacity crane, worked by four motors of 130 total horse-power. The second crane, of course, has been more recently installed than the first.

In the fusion of the ordinary carbon steel for guns, the materials employed are Swedish pig iron and puddled ball from Bilbao hæmatite pig iron. In order to convey an idea of the operation, a heat in the 16-ton furnace will be described.

The furnace was charged with 7.5 tons of Swedish pig iron and 9 tons of puddled ball from Bilbao hæmatite. These materials are charged straight into the furnace, the first charged being the pig iron. At 9.2 A.M. the charge was commenced, and melted at 2.40 P.M. The first iron ore addition of 60 kilogrammes weight was made at 2.50 P.M., and another of the same weight at 3.15 P.M., followed by another of 50 kilogrammes at 3.35 P.M. During the melting period and the following 45 minutes nearly all the silicon was oxidised. Some minutes after the third iron-ore addition, the ebullition of the bath commenced, which evidently proved that the oxidation of the carbon was energetically proceeding. The iron ore additions followed from time to time as the



PLAN OF UPPER END

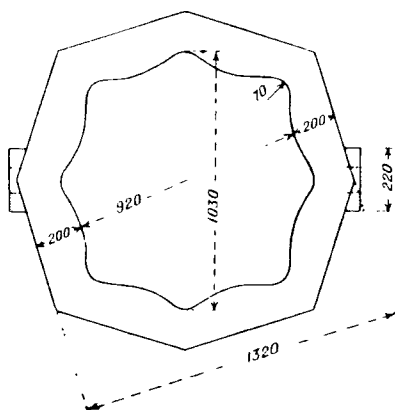


FIG. 1.

state of the bath indicated the necessity. The operation is conducted with the air-valve closed as much as possible, so that the metal should not become cold, nor become oxidised. The total additions of iron ore amounted to 350 kilogrammes. At 6.25 P.M. the colorimetric analysis of the small sample taken from the bath and very slowly cooled gave a percentage of carbon of 0.52 per cent., and as the quantity required in the steel must be between 0.45 and 0.55 it was decided to tap the furnace, making previously the suitable additions of alloys. These were ferro-manganese and ferro-silicon, putting 124 kilogrammes of the first and 99 of the second: the percentages required in the metal were 0.55 to 0.65 per cent. of manganese and 0.15 per cent. of silicon. This percentage is quite sufficient for obtaining a metal totally free from side and central cavities, except those at the top of the ingot and the pipe. The metal is poured into a Wellman ladle, previously well heated by producer-gas. The ladle is then transported by the 50-ton electric crane to the casting-pit, where the metal is poured into the mould.

Ingot Mould.—This is of cast iron, with a wash of refractory material, intended to retard the cooling of the metal at the top, keeping it fluid as long as possible, so that it may fill the space left vacant by the contraction of the metal in the rest of the mould. The mould both outside and inside has the form of a truncated pyramid (see Fig. 1). The sides of the inside pyramid, instead of being plane are curved surfaces joined to one another by rounding the edges. It seems natural that, since the elements of guns are cylindrical, the ingot moulds should also be of cylindrical form inside, and since also the steel, as it solidifies, crystallises in crystals whose axes are normal to the surface of the mould, the cylindrical form should be the best for obtaining good sound ingots without cracks. The reverse is what happens. The ingots cast in circular metal moulds have always a deep longitudinal crack, and thus are incapable of subsequent forging. In order to avoid the occurrence of cracks during solidification and subsequent cooling on the outside surface of the ingots, they are sometimes cast in refractory moulds. But though no cracks occur in ingots cast in such moulds, the long time spent in the cooling of a large ingot,

cast in such manner, produces a very coarse crystalline texture, almost impossible of being changed to the proper texture during the forging. The experience at Trubia with 40-ton ingots cast in refractory moulds has been totally adverse to their use as substitutes for metal moulds for the part of the ingot really utilised. When this is completely solidified and almost cold on its outside, it is taken out of the mould and is covered with ashes until it is completely cool. After this it is carefully examined for cracks, which are dealt with by the pneumatic hammer. As it is not an easy matter to get rid of them entirely by these means, the ingot is sent to the forging shop, where it is subjected to a slight preliminary forging, just sufficient to give it a cylindrical form. Any cracks which were not visible in the preliminary examination then appear, and are taken out in the lathe. Some very good metal is thereby lost, but in the finishing up of the forging no cracks appear, and it is possible to finish the pieces with the least possible excess in the dimensions required for the hardening.

Before describing the forging, it may be mentioned that, about half-way through casting, operations are suspended for an instant, while a very small ingot is cast from the ladle. This is intended for the full analysis of the metal, and for forging a test-piece for a preliminary tensile test.

In order to study the segregation phenomena in the unfinished steel, the head from a 16-ton ingot was divided through its vertical axis. One of the halves of this head is represented in Fig. 2. From it were taken the samples for analysing the carbon, manganese, phosphorus, and silicon. The samples were taken only in one half of the head, because it was presumed that the symmetrical parts of the other half must have the same composition, as the conditions of cooling were equal for both halves. The small ingot taken during the casting operation, which, owing to its very small dimensions, is free from the phenomena of segregation, and fairly represents the composition of the steel in the ladle (where it is supposed to be completely homogeneous), gave on analysis 0.56 per cent. of carbon and 0.57 per cent. of manganese. On comparing these percentages with those of the samples it is observed at once that there is not a very great difference between the

samples taken at the circumference of the head and those of the small ingot. But the difference is very great in the samples taken in the centre of the head. Here, segregation phenomena are in evidence, especially with regard to carbon. It is observed that sample No. 1, from the bottom of the head, has the same quantitative composition as the metal of the small ingot, but in samples Nos. 2, 3, 4 and 5 the percentage of carbon increases gradually, being in sample No. 5, four times greater than in sample No. 1. The manganese increases also, but less so; the silicon more than the manganese, while the phosphorus in sample No. 5 is double that of No. 1. The layer of steel, in contact with the ingot mould, represents very nearly the composition of the metal, in fact the percentage of the metalloids is less. The layer successively cooling from the outside yields to the inside layers a certain part of its metalloids, until the central part of the ingot is reached, which, being the last to solidify and cool, is therefore richer in foreign elements. As the ingot mould is not closed, and is not in the form of a symmetrical cube, the segregation phenomena do not occur in the ordinary ingot mould in the manner described by Howe in his classical book. "Iron, Steel, and Other Alloys," as the "Onion type" of freezing. If the mould is a perfect cube, and the action of gravity be assumed to be counterbalanced, the segregation phenomena should occur in a completely regular manner, in layers parallel to the sides, and the metal richer in foreign elements will be exactly in the centre of the figure. In the casting of large ingots the segregation phenomena must occur as described, because the top of the ingot is the last to cool, especially if, as is the case at Trubia and elsewhere, the head of the mould is of refractory material, which contributes, to a great extent, in keeping the metal fluid longer than if this part of the mould were of metal.

About twenty years ago Brustlein explained, in a report to the "Commission des Methodes d'Essai des Materiaux" in 1892, the lack of homogeneity of steel ingots and segregation phenomena in a manner very similar to that already explained in this paper, but without the aid of chemical analysis. His views as to segregation phenomena are in perfect accord

with the manner of solidifying the iron-carbon solutions, as Roozeboom has explained in his diagram.

Applying their theories to the solidifying of steel ingots for gun tubes, it is easy to explain why the percentage of carbon increases from the outside layer in contact with the walls of the mould to the centre of the ingot, culminating in the greater amount of carbon and of the other foreign elements in the upper and central part of the ingot which is the last to set.

Fluid Compression.—Fluid compression consists, as every one knows, in applying pressure to the steel while still fluid or semi-fluid. The process has acquired considerable development, and is extended to ingots of common steels, whereas it was at first only applied to ingots intended for the manufacture of guns or for the large shafts of ships. The older fluid compression method is that of Whitworth, whose patent was taken out in 1866, the chief object of which was to obtain cast steel ingots free from cavities.

The Whitworth process is undoubtedly a very good one, and, considered economically, it offers great advantages, but in practice not all the advantages of fluid compression are obtained. In one of the most important French steelworks, where this process is applied to the ingots intended for the construction of guns, the author has had occasion to examine some of them, and has found that the pipe at the top does not entirely disappear.

In order to demonstrate that the Whitworth fluid compression process gives homogeneous ingots, that is, ingots free from segregation, it would be necessary to demonstrate it practically by dividing a large ingot longitudinally, and taking many samples for analysis, from all parts, or at least in the upper third. It is certain that in present-day practice, with the judicious use of deoxidising alloys in the furnace such as ferro-manganese and ferro-silicon, and perhaps with a very slight addition of aluminium during the casting operation, it is possible to obtain ingots free from cavities, except at the very top, in the central part, as is seen in the head of a 16-ton ingot, represented in Fig. 2. In this, as in all similar ingots, a very sound and homogeneous (78 per cent.) total

mass was obtained. In favour of fluid compression it may be said that it causes the disappearance of the deep cracks, especially in the bottom of the ingot. Perhaps this is to be attributed rather to the lining of the inside of the ingot mould with refractory material. The cracks are always a serious defect, and sometimes, if ingot moulds of polygonal section without rounded corners are employed, and the block, after forging, is put on the lathe, they appear as dark lines along the total length of the piece, which correspond to the angles of the ingot. Certainly, in many cases the turnings do not break off when the tool cuts across the dark lines, but all the same the appearance of such lines does not suggest a very good quality of metal.

With regard to the improvement of the mechanical properties by fluid compression, the author must say that it is not very evident to him. Perhaps it is assumed that fluid compression during the last period of the process, when the metal is in a semi-fluid state and almost set, confers an effect similar to forging. In Whitworth fluid compression, after the expulsion of the gases, the press does not cause any deformation in the ingot, and there cannot be forging without deformation. Some years ago a new fluid compression process was patented by Messrs. Robinson and Rodgers, of Sheffield, in conjunction with Mr. Illingworth, of New York. This process has been described by Mr. A. J. Capron.¹ The advantages derived are that absolutely sound ingots are obtained free from cavities and pipe, so that the whole of the ingot can be utilised, without any waste. As it is possible to watch, during the compression, the top of the ingot and the setting of the liquated part of the steel, a great improvement in the quality of the metal can be obtained. The ingots are poured in the same place as they are compressed. The plant is very simple and economical, and can be operated by men without special training, and, the ingot moulds being in halves, the top and bottom sections are equal, which facilitates the rolling.

Another compression fluid process, which has become very well known and accepted during the last years, and is widely adopted in France, England, and Germany, is that patented

¹ *Journal of the Iron and Steel Institute*, 1906, No. I. p. 28.

by Mr. Harmet, of St. Etienne, which has also been fully described by him to the Iron and Steel Institute.¹

In concluding this part of the paper, the author would repeat that in his opinion the principal advantage to be derived from fluid compression lies in its economical aspect. When casting under ordinary conditions, it is possible to utilise from 75 per cent. to 80 per cent. of the ingot, while with compression it is possible to reach 90 per cent.

SECTION III.

HEAT TREATMENT.

Before proceeding further, it will be convenient to consider, at this point, the heat treatment most appropriate for gun steel.

The steel, having been cast in a mould of truncated cone shape, requires, of course, to be forged, in order to give to the gun or part of the gun the required form, which is always that of either a hollow or a solid cylinder, of varying length, with different diameters outside, and sometimes also inside. The annealing after the forging, the hardening—or hardenings, if it is necessary to harden more than once—and the subsequent tempering or temperings, constitute the series of heat treatment processes given to the steel for gun construction. Forging is not only necessary for giving the required form, but principally to change the crystalline structure of the large and medium-sized castings into one of finer grain, almost amorphous, which is essential for the best development of the physical and mechanical properties of a given steel for ordnance purposes. But as it is possible to obtain from a given steel, simply by heat treatment, without the aid of the press or of the hammer, physical and mechanical properties equal to those conferred by forging, it is only natural to ask if the forge is absolutely necessary, and whether, instead of casting ingots of the usual shape, it would not be possible to cast pieces of approximately the final form, and subject them afterwards to the heat treatment capable of modifying the texture developed by the cooling after the casting. This is a question which has been very much discussed for many years, and

¹ *Journal of the Iron and Steel Institute*, 1902, No. II. p. 146.

opinion seems on theoretical grounds to be in favour of the suppression of the forge, but on practical grounds the forge is retained, and there is no indication whatever that it is likely to be dispensed with.

The manner of fixing the amorphous structure obtained by heat treatment is to cool the piece very quickly. For thirty or more years these facts appear well established, yet the specifications of all the armies and navies of the world continue to require the use of the forge in the manufacture of gun steel, notwithstanding that eminent metallurgists have demonstrated the possibility of making very good pieces for gun construction without the aid of the forge. The tests were certainly made with small pieces many years ago, but an enterprising firm in Sweden now makes guns up to 24-centimetres calibre without forging. In 1882 Mr. Pourcelet, in a paper read before the Iron and Steel Institute, described the series of operations which constituted the whole process at the Terre-Noire Steel Works in the manufacture of steel hoops for 4-inch guns. These hoops must, of course, satisfy the same specifications as those required for the forged metal. After casting the steel with the necessary additions of ferro-silicon for freeing the ingots from cavities and securing a perfectly sound metal, a heat treatment was given to the hoops, which consisted in heating them to a yellow heat and hardening them in an oil bath of fixed weight. After being cooled in the liquid they were afterwards reheated to a temperature which varied from light cherry-red to a dark cherry-red, in accordance with the chemical composition of the metal. The hoop was then cooled in a bath of the same liquid, where it remained until it was perfectly cool. By the first hardening the crystalline grain of the metal was transformed into a finer and homogeneous grain. The second hardening confers on the pieces the molecular equilibrium corresponding to their chemical composition.

The result of these two operations was a true hardening, inasmuch as the piece was heated to a higher temperature than that of the transformation point, and by this the size of the original grain was changed, and the new structure fixed by subsequent cooling in a large quantity of oil.

The second heat treatment, also called hardening by Mr. Pourcel, was, rather than a hardening or annealing, a true tempering, which caused the disappearance of the strains originated by the hardening, and increased the ductility, which had been lowered by the first operation. Sometimes it was necessary to repeat the two operations, if the tenacity of the metal was less than that required by the specifications, or only the second if the ductility obtained was less than required. Mr. Pourcel had some doubts at that time if this process, applied to guns of a calibre larger than that of 4 inches, would give the same excellent results. His conviction inclined him to take the affirmative side of the question. Undoubtedly he had thought the subject out in a logical manner, and it is not easy to understand why such ideas as these, so well grounded, have not been adopted by metallurgists. The Swedish Steel Works, the Aktiebolaget Bofors Gullspång, for many years has been successfully applying steel as cast to the construction of guns. Working systematically, and passing gradually from the simple to the complex, they began by producing field guns, followed by fortress guns, and finally essayed the manufacture of coast and navy guns, commencing with a quick-firing gun of 15 centimetres in calibre. The United States of America even used a gun of this type, the trials of which were commenced in 1902, and gave exceedingly good results.

Recently the author has ascertained that the Bofors Steel Works has constructed guns of 21 and 24 centimetres, whose elements have been simply cast and afterwards subjected to heat treatment. Of course, the elements for the field and fortress guns are also subjected to proper heat treatment. These are facts the importance of which it is impossible to deny. They afford evident proof of great advance in the way of applying heat treatment alone without forging the elements of guns. The author thinks, however, that it is no easy matter to cast 10-inch and 12-inch gun tubes 50 calibres in length, moulding them in a refractory mould.

There is another reason against the acceptance, by Governments, of this process of manufacture. It may happen that, despite all the precaution and care taken in the finish and

casting of the elements in order to obtain pieces absolutely free from cavities, a cavity may occur in the thickness of a tube without being detected during the mechanical work, and may cause the bursting of the gun when firing.

Hardening and Tempering.—If forging is necessary, or presumably necessary, in order to obtain first-rate elements for the manufacture of the guns, the hardening process is also necessary for the tempering.

To obtain these properties in the highest degree must be the supreme object of the metallurgist. The author, during many years' experience in the manufacture of steel both by the crucible and open-hearth processes, for 24-centimetre guns of 45 calibres in length, has found that however well conducted the forging, the transformation of the crystalline structure into one of amorphous, or fine grain, is only obtained in the highest degree (if the forging is not completed) by hardening and tempering, and sometimes more than one and more even than two such operations. As it is not the chief aim of the hardening (in semi-hard steel of the type used for gun construction) really to harden the metal, and as it is easy to obtain the required mechanical qualities by forging only (followed by an annealing), it would seem that the hardening might be dispensed with. However, as many years ago hardening in oil was introduced with excellent results, the process was retained and formed part of the specifications. The study of iron-carbon alloys has shown the great advantages that can be derived from an adequate heat treatment of the steel.

The most important point in forging is to fix the limits of the temperature within which it is possible to conduct it. The highest of course must be the temperature at which the cohesion of the grains of metal begins to weaken and the grains to separate; this last action is due also in part to the gas evolved from within the mass. The generally admitted hypothesis is that this gas is carbon dioxide formed by the oxygen passing through the metal and combining with the carbon, though it is possible that carbon monoxide and other gases such as nitrogen and hydrogen are also given off. When a steel is in this state it is said to be burnt, a condition which is chiefly distinguished from the overheated state by the

separation of the grains. To this can, perhaps, be added the great thickness of the ferrite network, which is found when the steel cools through the temperature interval, Ar_3 Ar_1 . It can be said that the upper limit of temperature for forging the steel for gun construction is between 1100° – 1000° C. The lower limit must be that of the transformation of the metal, as below this temperature the structure is not changed. This is the natural and logical limit; but some authors, especially Tschernoff, think that forging at lower temperatures is convenient. But certainly Tschernoff would find it difficult, and even impossible, with the means at his disposal when he wrote his celebrated paper, to forge the large mass required for great guns at temperatures below the transformation point.

Coming now to the practical aspect of forging large ingots for gun construction, it must be emphasised that it is necessary to heat them very carefully and slowly. If the temperature of the furnace, when the ingots are introduced, is rather high, it is better to pre-heat them. Certainly the temperature of the furnace is suddenly lowered by the introduction of cold ingots, which naturally take a great part of the heat lost by the furnace; but this heat, taken up suddenly, causes a sudden dilatation of the outside of the ingot with the natural consequence of cracks, and it may occasion the breaking of the ingot across. This happens especially if the metal is somewhat hard. The two reheating furnaces for the great forging press at Trubia are of the Whitworth type. Their doors are worked by hydraulic power. The largest ingots, until recently, forged at Trubia, were 42 tons weight, suitable for the forging of the tubes and other elements of the 24 centimetres and 45 calibres. As an instance of solid forging, that of the A tube for the 24-centimetre gun may be taken. The ingot on being taken out of the mould was 16 feet 6 inches in total length, of which 13 feet corresponded to the pyramidal part, cast in the metal mould, and the other 3 feet 6 inches to the conical part cast in the refractory material attachment. The diameter at the two bases of the tronco-pyramidal part was respectively 4 feet 10 inches and 4 feet. The mean diameter of the truncated cone part was

2 feet 8 inches (see Fig. 3). The ingot free from all cracks, and reduced to a diameter of about 2 feet 8 inches by the previous forging, was put in the furnace, where it was heated carefully and very slowly during 30 hours, which is a sufficient time for the whole mass to become well and uniformly heated throughout. The temperature, as already stated, was 1100° C. approximately, and the forging operation is suspended

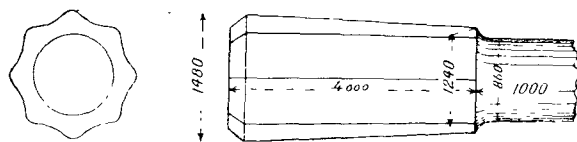


FIG. 3.

at 700° C., when the ingot is put into the furnace again. The operation was finished in three heats, and the time taken to complete it after the first heating was 15 hours. The tube weighed 18.5 tons after forging, and its dimensions are given in Fig. 4. For the hollow forged tubes and hoops, 40-ton ingots are also employed. From each ingot two B tubes are forged. The operation of removing the cracks and

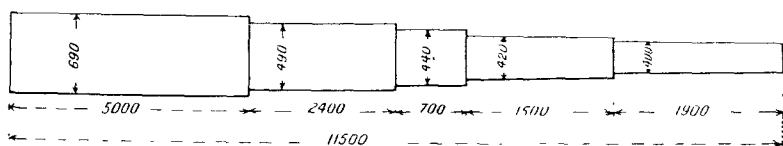


FIG. 4.

also of the previous forging are the same as those practised with the ingots for the A tubes. Afterwards the blocks are sent to the large boring machine supplied by Sir William Armstrong, Whitworth & Co., where they are bored from both ends at the same time to a diameter of 1 foot right through. When this operation is finished, the ingot is cut into two halves. The reheating is performed in the same furnaces and conducted with the precautions already described in the case of the A tubes. The duration of the first heating is 30 hours,

and the first operation practised is that of enlarging the bore in a Whitworth drawing press. When the operation is finished throughout the length of the tube, the latter has a larger diameter and less thickness than at the beginning of the operation. The tube then goes again to the furnace, and after careful heating the forging is continued, and it is again stretched on mandrils of different diameters. The full operation involves four reheatings, and the total duration is from 13 to 14 hours, the final dimensions of the tube being: total length, 17 feet 2 inches, and outside diameters 2 feet 4 inches, in a length of about 20 inches, and of 2 feet 3 inches in the rest of the piece. The inside diameter is 14 inches. The great hoops are forged by means similar to those employed with the B tubes. Sometimes when the ingots from which they are obtained are not very long, the hole for the mandril is punched in the press after being carefully reheated, instead of being bored in the machine. This operation is made in one heat, the hole being driven by a conical steel tool which enlarges and lengthens the hole. When half of the ingot has been treated, it is turned and the operation repeated on the second half. It is preferable to bore the ingot, because in this manner the steel of the central part, with a chemical composition distinct from the rest of the ingot due to segregation, is eliminated. Forging after boring must be practised (in preference to forging the solid ingot) when possible, because the action of the press is more energetic in the first than in the second case, the press acting on less thickness of metal. With hoop No. 1 for a 24-centimetre gun, forged hollow, the following notable tensile results were obtained after the full heat treatment. At one end of the hoop, the mean result of three test-bars was 52 tons per square inch tenacity and 17 per cent. elongation measured in 4 inches, and at the other end 54 tons tenacity and 17 per cent. elongation, conditions better than those ordinarily specified for nickel gun steel.

Annealing after Forging.—This is an indispensable operation in the manufacture of steel for guns. If it were possible to finish the forging of a piece in one heat only and in such a manner that the whole piece was finished at an even and

correct temperature, then, in this case only, the annealing operation could be dispensed with. Some think the operation superfluous, as the piece must be heated to a higher temperature for the hardening process or to a temperature at least equal to that required in the annealing. But forging cannot be conducted in the ideal manner just described, nor is it possible, in the last period, to heat the A tubes for large guns uniformly throughout their length. The lack of uniformity in the finishing temperature requires that the pieces should be annealed before passing to the machine shops, to be prepared for the hardening process. After annealing, the metal will be in the best possible state for the turning and boring operations, and the pieces are less likely to suffer deformation during handling. In being reheated preparatory to hardening they retain their shape better, and in taking them out of the furnace for cooling they are less likely to bend and they undergo less deformation in the process of hardening. The slight deformation in the finishing mechanical operations is also avoided, and exposure to direct sunlight has less effect. Owing to these special circumstances, the Government of the United States specify, in the construction of howitzers that the shops of the Niles Co., in Hamilton, Ohio, must be always at the same temperature. At Trubia, for the annealing after forging, the same furnaces are used as for the hardening. The operation is conducted very carefully, the temperature in all parts of the furnace, and of the piece, being measured with a Le Chatelier pyrometer. When furnace and piece are at the proper uniform temperature, the gas is shut off and the piece cools slowly in the furnace. Of course the annealing temperature must be above the transformation point. The elements for field guns are annealed in a special furnace. Taking into consideration their small mass, they are not individually annealed, but eight or ten are put into the furnace at a time. They are heated to 900° very carefully, and after reaching this temperature they are slowly cooled. The author thinks that the advantages obtained by annealing, after forging, are more marked in the elements for the field guns.

SECTION VI.

HARDENING AND TEMPERING.

The author has already endeavoured to demonstrate the necessity of subjecting to a certain heat treatment the steel for gun construction. This heat treatment comprises one or more hardenings and temperings as required in order to satisfy the specifications; and the heat treatment must comprise precisely the hardening and tempering. It is also well to insist on calling the second operation tempering and not annealing, because in preparing the pieces for this operation they are heated to a temperature below the transformation point. If they were heated to a temperature above that point and then cooled slowly the structure of metal created by the hardening process would absolutely disappear. Perfect hardening indicates in the metal a state of unstable equilibrium at ordinary temperature, because this state is that of equilibrium at a temperature above that of the transformation point. Mr. George Ede claimed that the hardening in oil for the elements of guns originated in England at Woolwich Arsenal. The process originated in consideration of the benefits derived from the hardening in oil of hard steel for tools, and in treating the milder steels employed in the manufacture of guns in the same way it was found that the mechanical properties were improved. Tschernoff, in his celebrated paper on the Working of Steel, says that for securing uniformity and fine grain it is necessary, after finishing the forging, to reheat the piece to a temperature above the point *b*, which is that of the transformation in his scale, and then to fix the amorphous texture by rapidly cooling it; this amorphous texture will be more surely obtained, the rapidity of cooling being the same, the less the point *b* in the reheating be exceeded.

Tschernoff and Woolwich Arsenal coincide in the treatment after forging to be given to the elements for gun steel, and this has led perhaps to the process being adopted by some manufacturing firms in other countries. At the Krupp works the elements for guns are said not to be hardened and tempered. The author has explained in another part of this

paper the reasons why the metal must be subjected to heat treatment, and it is not necessary to repeat them here. In England and in the United States oil is exclusively employed as a refrigerant liquid; in France and Spain (Trubia Arsenal) water is used. Between hardening in oil and hardening in water, the temperature (always above that of transformation) being equal, the difference is very considerable, owing solely to the rapidity of cooling. In accordance with the remarkable work of Le Chatelier, which forms a very interesting paper in the *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, No. 9, vol. cvi., there is a well-marked difference in the rapidity of cooling a piece in water or in oil. This was well known from the time hardening was first practised, but Le Chatelier measured mathematically the rate of cooling. He operated with very small pieces, and took into consideration the extreme interval of temperature, which must be rapidly passed for realising the hardening. Knowing that the recalcence phenomenon is never produced on cooling to a temperature superior to 700° C., and that the tempering is not influenced by temperature down to 700° C., he only took into consideration in his experiments the time spent in passing from 700° C. to 600° C., which time, all the remaining conditions being equal, gives a very accurate notion, almost mathematically exact, of the rapidity of cooling, and therefore of the energy of the hardening. The central part of the sample, hardened in pure water, employed 5 seconds in passing from the temperature of 700° C. to that of 600° C. In the oil hardening for passing the same interval 43 seconds were required, that is, the time was seven times longer than with the pure water. It must be said that in this experiment of Le Chatelier with oil, the rapidity of cooling was much less in the interval of 190° C. to 100° C., in which interval 30 seconds were spent. It is natural that this happens with all the refrigerant liquids, but in oil it is much more marked, and the explanation is, according to Le Chatelier, that during the operation the oil is decomposed and the gaseous bubbles cause a circulation of the liquid, which must cease at the end of the cooling. From these experiments, confirming by a scientific method all that was known, it is possible

to state what will be the difference of hardening which two elements heated to the same temperature and cooled in two liquids, both also at the same temperature, should take. If the elements hardened in both liquids were intended for large guns, and if they should possess great thickness, there would be sufficient reasons for thinking that none of the pieces would possess, at the ordinary temperature, the structure which it possessed at the beginning of cooling. But surely the piece hardened in water should be the nearest to this structure. Benedicks, in a paper recently read before this Institute, has made experiments on hardening in a manner very similar to that of Le Chatelier. He says that the most important factor in the rapidity of cooling is neither the conductivity nor the specific heat, but the latent heat of vaporisation of the liquid. The specific heat has a secondary influence, and it is possible to dispense with the heat conductivity. The necessary conditions for obtaining from a given bath an efficacious hardening are as follow:—

(1) A high latent heat at vaporisation.

(2) A low temperature, in order that the vapour bubbles, generated in the surface of the metal, might be easily condensed in the ambient liquid. Whatever may be the predominant factor in the rapidity of cooling, the hardening in water will always be more energetic than the hardening in oil. Therefore, there is no doubt that the hardening in water will require a subsequent tempering, more energetic at a higher temperature than would have been necessary if the hardening had taken place in oil, in order to enable the metal to stand the tensile and shock tests specified. Really the hardening point, so that in submerging the piece in the refrigerant liquid the cooling might begin when the steel is yet at a higher temperature than that of the transformation. At the Trubia Arsenal, in the hardening of the elements for gun construction, water, as already mentioned, is employed as refrigerant liquid. The hardening plant is shown in Fig. 5. The reheating furnaces are vertical, and are heated by gas from three Dowson producers. The large furnace is capable of taking pieces 40 feet in length, and has four inlets for the gas, regularly spaced. It is built

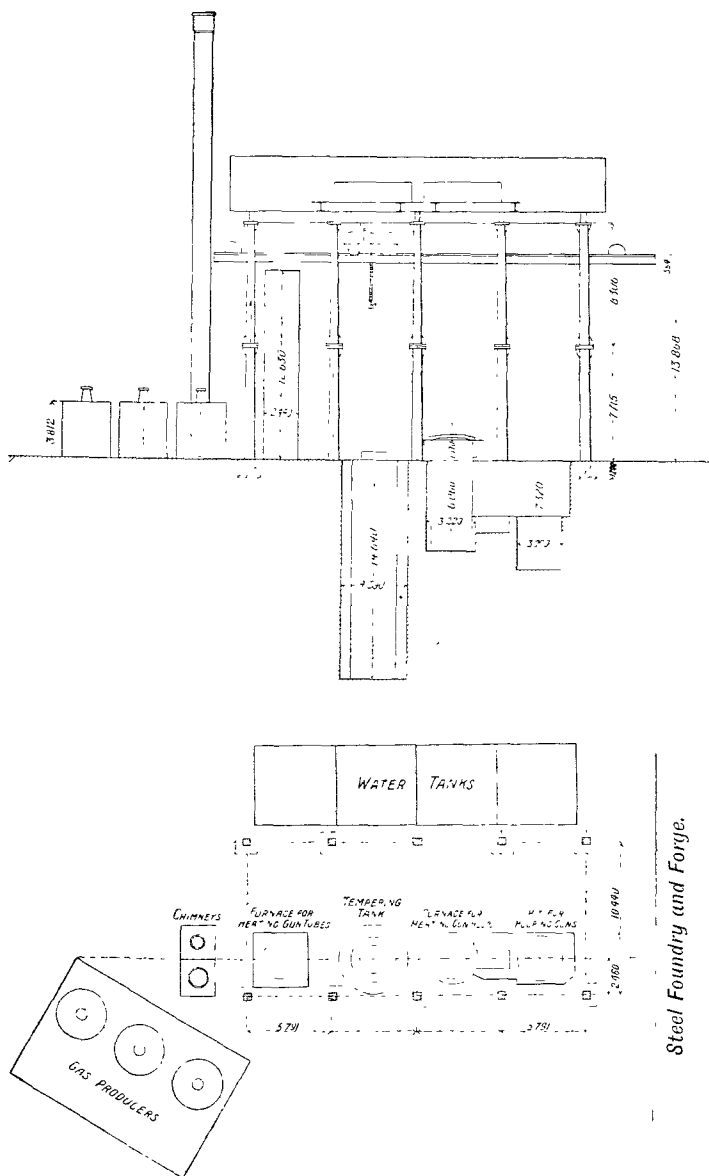


FIG. 5.

upon the ground floor, and, as is natural in these conditions, the tubes are manipulated through a lateral port, hydraulically. The second furnace is of greater diameter than the first, and its length is 26 feet. It is intended for the reheating of the B tubes and hoops, also for the tubes of the medium guns up to 6-inch calibre. The water tank is situated between the two furnaces, and has the dimensions stated in the drawing. The water, at the time of the cooling, has a temperature of 20°C . A 35-ton overhead travelling crane is driven by a rope worked by a steam-engine, and serves the whole of the hardening shop. When this plant was installed twelve years ago the intention was to use oil as a refrigerant liquid, as was the practice at Trubia with all the guns manufactured before that date, which did not exceed 6-inch calibre. In accordance with this idea, four tanks capable of containing more than 100 cubic metres of oil were conveniently installed at the top of the building, under the roof, and another four tanks of the same cubic capacity were installed at the outside of the shop, and on a level lower than the ground floor. The hardening tank is in communication with the higher and lower tanks by means of a system of pipes which are worked by the necessary pass-valves. A steam pump can elevate the liquid, when it is cooled, from the lower refrigerant tanks to the higher, and during the hardening it is possible to maintain a constant current of oil in such a manner that that of the hardening tank should not take a temperature so high that the piece instead of being hardened is annealed.

As is seen from the drawing, the capacity of the shop is limited to the hardening of elements for 10-inch guns and 45 calibres in length.

The measuring of the temperatures is done by the aid of the Le Chatelier thermo-electric pyrometer, registering the temperature of the tube or hardened piece at different points in order to distribute the heat in such a manner that the temperature may be uniform. Undoubtedly the best method is that followed at Woolwich Arsenal, with the long tubes for the 12-inch guns of 45 and 50 calibres, where four or five Le Chatelier pyrometers are installed, with registering apparatus,

and regularly distributed all along the tube; that is both convenient and necessary when operating with tubes for guns of 54 feet in length, or perhaps more, with the excess length left at both ends for the test-pieces. It is really very difficult to heat uniformly the long pieces of variable thicknesses, and therefore to harden them. The difference of operating as physical experimenters do in their laboratories with samples of some grammes weight, and of dealing with 15, 20, 25 and 30-ton pieces, as is the daily practice of the manufacturers of gun steel, is enormous. By carrying out the hardening in the ordinary way, the cooling of the metal begins at the inside and outside surfaces at the same time. If the cooling is more rapid at the inside the interior layers near this surface will be compressed and the exterior layers will be in tension. The reverse will happen if the cooling is more rapid at the

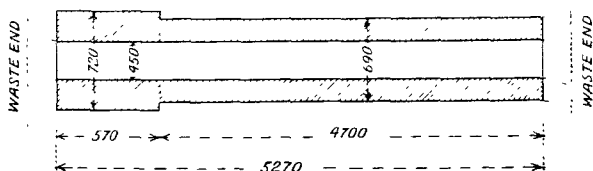


FIG. 6.

exterior than at the interior surface. The best condition for the resistance of guns is that the first case should occur, and then not only will the improvement in the structure derived from the hardening be obtained, but the steel will be in ideal condition for withstanding the pressure of the powder gases. Upon such considerations was established the St. Etienne process, which consisted in cooling the tubes on the inside only. But this process had the great disadvantage that if certainty was attained that the piece was in the best conditions for the resistance of the pressure of the gases, the uniformity of the hardening, and therefore of the structure due to uniform rate of cooling throughout the whole piece, was lost.

If tensions or compressions have been produced the layers of metal must be distended or compressed. Knowing the tensile characteristics of the metal, it is very easy to measure the intensity of the tensions or compressions, as they are

of a purely elastic character, and it is possible to plot a diagram representing the variation of tensile strength in terms of the thickness of the piece. In the ordinary practice of conducting the hardening operation in the tubes intended for gun construction the result generally is that the outside surface is compressed, that is to say, the contrary of what

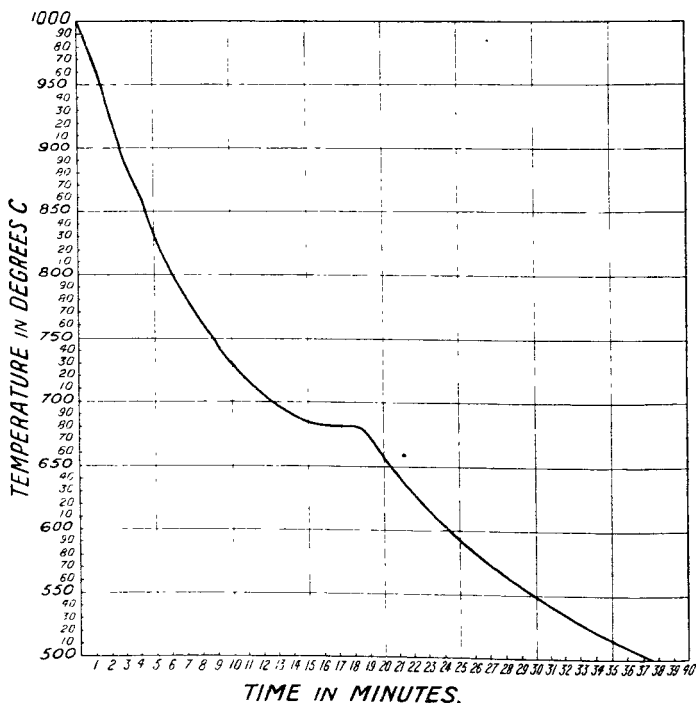


FIG. 7.—Cooling Curve for Ordinary Gun Steel (Carbon Steel).

must be most convenient for the strength of the gun. With hardening in water, and dealing with carbon steel of 0.5 per cent., the tempering operation is absolutely necessary. Even when the piece has been heated and hardened with absolute uniformity, and the elastic tension caused by the hardening should be the most suitable for the strength of the gun, the tempering of the piece would be absolutely necessary, because the hardness due to the hardening would make it very difficult, if not impossible, to machine the piece in

ordinary conditions of work, and the tensile, bending, and dynamical properties would not be in accordance with the specifications. In hardening in oil, in nearly all cases, tempering at a very low temperature, in order to cause the disappearance of the light stresses originated, is sufficient, but in water hardening, and with metals of 0.5 per cent. of carbon,

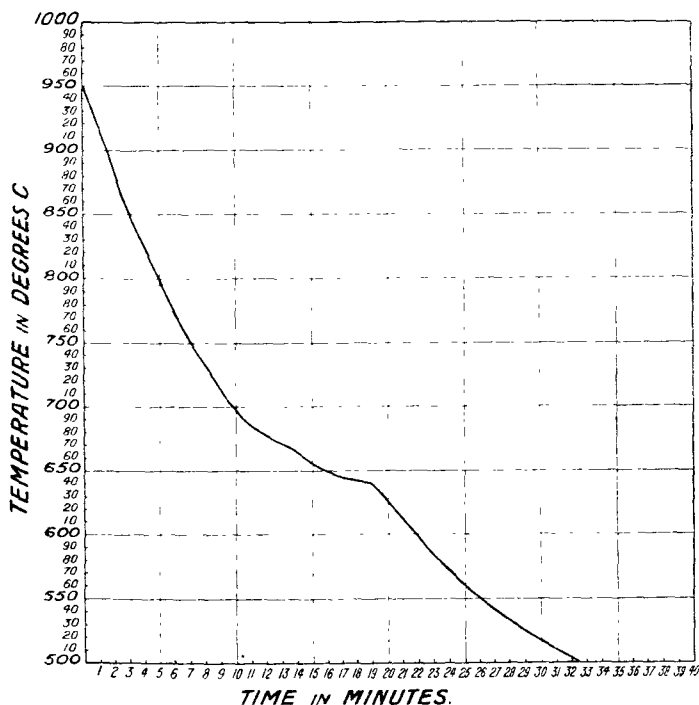


FIG. 8.—Cooling Curve for Nickel Steel.

the tempering temperature will be near that of the transformation point.

Ordinarily that necessary for obtaining the best tensile properties is about 600° C. It is clear that if these properties, after the heat treatment, are deficient from those specified, or lower than those required, it would be necessary to submit the piece to fresh heat treatment, raising the temperature of hardening and keeping constant that of tempering, or the same result can be obtained by giving

the piece a new hardening at the same temperature and lowering that of tempering. If, on the contrary, the tenacity were higher and the ductility less than required, the results can be rectified by giving the piece a new tempering at a higher temperature.

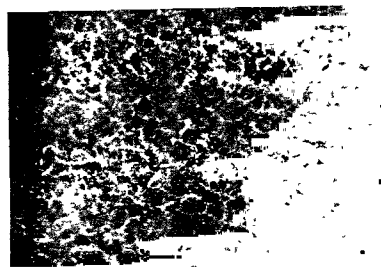
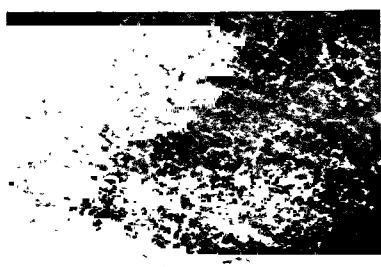
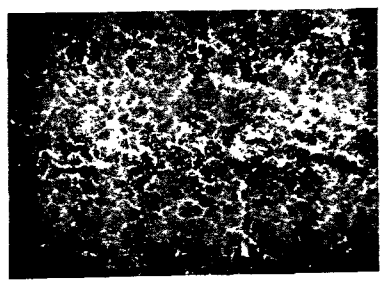
COOLING CURVES AND MICROSTRUCTURES.

Even though the cooling curves of different types of steel are well known, the author believes it useful to give in this paper those of both types of artillery steel, carbon and nickel steels (Figs. 6 and 7), the latter being employed in the manufacture of field and medium guns. Owing to certain difficulties at the Trubia Laboratory, it has not been possible to obtain the curves of both steels from the liquid state. The range of cooling is therefore from 1000°C. to 500°C. for ordinary steel, and from 950°C. to 500°C. for nickel steel. Within this range are found the transformation points, so important for the proper treatment of the metal in all the heat treatment operations. Observing first the cooling curve of the ordinary steel, it is seen that the cooling is generally in accordance with the well-known Newton's Law, and that the curve has only a well-marked point A_1 at 684°C. At this temperature the curve is converted into a horizontal line for a length of 20 millimetres, indicating 200 seconds or 3 minutes 20 seconds. The temperature is therefore constant during this period, indicating complete equilibrium of the two component systems, iron-carbon. This is the range during which the solid solution or martensite, stable at a temperature above 684°C. , is transformed into ferrite and pearlite constituents, with less than 0.89 per cent. carbon, stable at a temperature below 684°C. for this particular steel. Certainly it would not have been difficult to calculate the heat of transformation of this steel, taking into account the weight of the sample and its specific heat. From the transformation range the rate of cooling diminishes, in accordance also with Newton's Law. Nickel steel shows also a small point of transformation at 656°C. , the horizontal not

NICKEL STEEL.



No. 1.—Annealed at 900° C. after forging.



No. 2.—Hardened at 900° C. in water, and tempered at 580° C.

	<i>Analysis.</i>	Per Cent.
Carbon	0.326
Manganese	0.475
Nickel	2.207

Etched with picric acid.

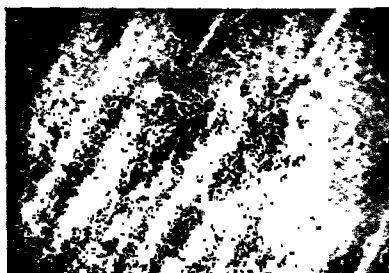
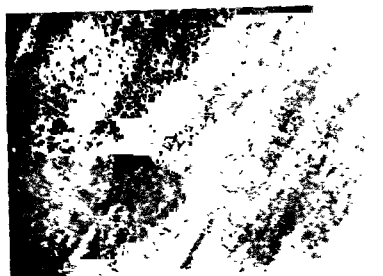
Magnified 50 diameters.

PLATE XXXVI

ARTILLERY STEEL.



No. 1.—Annealed at 900° C. after forging.



No. 2.—Hardened at 850° C. in water, and tempered at 580° C.

	<i>Analysis.</i>	Per Cent.
Carbon		0.411
Manganese		0.470

Etched with picric acid.

Magnified 50 diameters.

being as well marked as in the curve of the ordinary carbon steel. All that has been said on behalf of this is applicable to ternary nickel steel.

Photomicrographs have been taken of both types of steels in the states of annealing after the forging, and of hardening and tempering (Plates XXXV. and XXXVI.).

DISCUSSION.

Mr. A. GREINER, Vice-President, said the paper dealt with a very interesting subject. At the Cockerill works they were engaged in the manufacture of guns, but not of any size larger than 8-inch calibre. Interesting questions arose in connection with the comparison between crucible and open-hearth steel, and it might be that, under certain conditions, open-hearth steel would be equal in quality to crucible steel. It was of course necessary that great care should be taken, that first-rate materials should be used, and that the furnace should be capable of working at a very high temperature to give metal of a quality equal to that attained by high-class crucible steel.

There was, however, one theoretical consideration, and that was the result due to the boiling of the steel, which seemed to him to be absent in the open-hearth process. That important phase was met with in electric furnace work, where the temperature of the bath was sufficiently high to cause boiling, and there was no doubt that owing to that boiling, the metal produced was quite equal to crucible steel. That did not imply that steel made in the open-hearth furnace might not be of very good quality for gun manufacture.

The difficulty of obtaining a sound ingot was recognised, and it was not at all easy to line a mould with refractory material which would stand the necessary high temperature. Generally the steel cast in such moulds was liable to be less sound than that cast in iron moulds. He believed that the reason for that was that when casting was carried out in a refractory lined mould, crystals formed on the edges, and when the forging was turned dark lines of pearlite or some other material were revealed, and for that reason he believed it was preferable to cast large ingots in iron moulds.

With regard to the question of compression, as far as his experience extended, it went to show that the process was a very good one, and he had great confidence in the Harmet system.

There was a reference to the casting of guns direct, at Bofors, but to his knowledge no very large guns had been so cast. He recognised that with suitable arrangements it might be possible to cast large guns, but it should be understood that the difficulties to be surmounted were very great. In the case of a large gun it might be necessary to deal with pieces of metal measuring from 60 to 70 feet in length, and it was not possible to obtain such pieces by casting. Mr. Greiner illustrated by diagrams various methods of casting at an angle in order to get rid of the objections arising from excessive pressure, and went on to say that he had never himself cast guns in that way, but had obtained good results from such a method in the casting of armour-plates. Those armour-plates were intended for the defences of Antwerp. They were usually made by forging, under the press, ingots of from 20 to 40 tons weight, followed by annealing and tempering. Tests were made on pieces 8 feet square and 10 inches thick, which had to withstand four blows from a 6-inch gun with a striking

velocity of 500 metres per second. A plate simply cast on the inclined system and afterwards treated like the others had given as satisfactory a test as the forged plates.

MR. J. M. GLEDHILL, Member of Council, said the paper was a very interesting one. He was reminded, as one associated with the manufacture of guns, that there were clauses in some of the British Government specifications under which anyone divulging State secrets connected with that kind of work was liable to five years' penal servitude, so he had to tread rather warily in that connection. The author had given a scientific description of the treatment of forgings, but, if he might say so, he was not quite up to date in one point—namely, in connection with the subject of cracks in ingots. Ingots that were intended for the production of gun forgings ought not to have any cracks; they ought to be made with a process that prevented cracks, because although an ingot might possess cracks which could be removed by machining, there was some doubt as to whether the material was even then quite free from cracks. On the principle that prevention was better than cure, it was better to have a process which did not give those serious faults. He was now coming to rather a delicate subject—namely, the Whitworth compression system. His firm for the past twenty-five years or more had only made ingots in refractory moulds, and subject to fluid pressure, and, as the author said, the less they altered the section or form of the ingot that they were going to produce the better; consequently all their ingots were cast in circular section for the manufacture of gun steel. They were all subject to fluid pressure, with a total maximum of 12,000 tons on ingots up to 12½ tons. No turning was done on those ingots at all, but as proving the excellence of the surface, when they were machined to the extent of ¼-inch each side those ingots showed no cracks of any kind. With that exception, the paper was excellent, and it was evident that they knew something about the manufacture of heavy ordnance at the Spanish works. The Institute was indebted for that valuable paper, which was of a very special nature. It was an age of big things. There were 25,000 and 30,000 ton battleships, and forgings were now made for 15-inch and 16-inch guns. There were even whispers that the next gun was to be 18-in. bore, probably weighing 150 to 200 tons.

MR. W. H. ELLIS, Member of Council, congratulated General Cubillo upon having shown what progress had been made in Spain in that most interesting subject. As he had not previously been able to read the paper, he did not feel able to speak very fully thereon. Alluding to Mr. Gledhill's remarks, Mr. Ellis said he had had considerable experience in working Whitworth fluid-compressed ingots, and all the ingots of that character which he had worked with had been most satisfactory. He did not want Mr. Gledhill or other members to feel that the Whitworth fluid process, which was so early introduced, commanded the field altogether; and he thought that the

author had not quite done justice to the Harmet system in the somewhat slight allusion he had made to it. Mr. Gledhill alluded to ingots of far more weight than were dealt with by the Harmet process, and the Harmet process was only excellent in relation to ingots of moderate dimensions, because, unfortunately, the curve of pressure went up very largely relatively to the weight of the ingot, and it was problematical—it was certainly not proved at present—what weight of ingot could be produced satisfactorily by the Harmet process. He doubted whether it could deal with a 60-ton ingot, much less the 120-ton ingot referred to by Mr. Gledhill. If the author, while in Great Britain, made further inquiries as to the progress which had been made with the Harmet system, he would probably find that it was confined to gun work where the ingots did not exceed 30 tons in weight. The author stated that when casting under ordinary conditions it was possible to utilise from 75 per cent. to 80 per cent. of the ingot, while with compression it was possible to utilise 90 per cent. He agreed with the latter statement, but he did not agree that anybody in Great Britain, or in any other country so far as he knew, had found it possible to utilise 80 per cent. of the ingot made under ordinary conditions with work of such a high-class nature as gun work. It was that very fact which had necessitated the introduction of such methods as the fluid process, the Harmet and other processes, for the purpose of enabling the larger percentage to be dealt with. He thought the author was far too sanguine in naming that figure.

Mr. A. J. CAPRON (Sheffield) said that without going fully into the question of the merits of the compression processes on the quality of the steel, there was one practical advantage following the use of the Whitworth, the Harmet, or the Jessop method when dealing with ingots of the size referred to by Mr. Gledhill which he would like to emphasise. The point he desired to make was the greater percentage of ingot which could be used, to which Mr. Ellis had referred. That had the further advantage of reducing the total weight of metal which had to be dealt with, and was a practical advantage quite apart from the actual improvement in the quality of the steel itself.

The PRESIDENT, in proposing a hearty vote of thanks to the author for his paper, pointed out that General Cubillo had made a journey from Spain in order personally to present the paper to the Institute. The General would reply in writing to the points raised in the discussion.

CORRESPONDENCE.

General CUBILLO, in reply, thanked the members for the very kind manner in which they had received his paper. Dealing first with Mr. Greiner's remarks, he considered that by means of the open-

hearth process it was possible to obtain a steel for guns fully equal, as regards high quality and excellent mechanical properties, to that produced by the crucible process, provided that care was used to select only the purest possible raw materials, and to conduct the operation in as careful a manner as that prescribed in the paper, in order to obtain perfectly sound ingots free from gases. The subsequent process of heat treatment was, of course, the same whichever system was employed. The reason why details of the tensile tests to which steel for guns was subjected were not categorically stated in the paper, was that the testing methods practised in different countries differed little from one another and were well known. Latterly, the test-bars for tensile and impact tests had been taken across the grain of the parts and not in the longitudinal direction of the grain, the reason of course being that the maximum strain which gun tubes had to resist was a tangential one. The author was entirely in accord with what Mr. Greiner said with regard to the great difficulties of casting tubes and other elements of 12-inch guns, especially the internal tubes, which were of the same length as the whole gun. He was unable, however, to offer any explanation as to how they overcame that difficulty at Bofors with smaller guns of 21 and 24 centimetres calibre. Neither had he had any experience in the practice of casting plates for armoured ships at an angle, although he thought such a method would certainly be possible by making use of large sinking-heads at convenient distances apart.

In reply to the remarks of Mr. Gledhill, he was of opinion that cracks were not caused by subjecting the ingots to fluid compression, but he was quite certain that by taking the precautions indicated in the paper absolutely sound gun tubes could be produced. If the cracks could not be got rid of by means of the pneumatic hammer before finishing the forging, it would be necessary to interrupt the forging operation for the purpose of removing them with the shears, or by means of a cutting tool under the press. With regard to fluid compression, the author reaffirmed that he was convinced of its advantages solely from the point of view of economy and as a means of getting rid of cracks. The compression of the ingots in the fluid state did not improve the physical and mechanical properties of the steel, so far as was known, and no one could affirm that it did, without first making tests on two ingots of the same chemical composition which had undergone the same heat treatment, one of them having been compressed in the fluid state and the other allowed to cool in the ordinary way. Until the question had been proved in that way, he saw no reason to change his views. Lastly, Mr. Gledhill himself, in discussing Mr. Lambert's paper read before the Institute in 1908, plainly declared that the chemical composition of large steel ingots for forging tubes for big guns differed at the two ends of the ingot, and that that was due to segregation phenomena. Since Mr. Gledhill was undoubtedly referring to ingots which had been subjected to fluid compression, he plainly inferred that ingots

absolutely homogeneous throughout their length could not be obtained by compressing the steel.

With respect to Mr. Ellis's remarks, he was convinced that by the proper use of deoxidising agents in the bath, whether added by themselves or in the form of an alloy of silicon, aluminium, or manganese, it was possible to obtain the ingots without blowholes, of which 75 to 80 per cent. of the whole could be utilised. On the occasion of his visit to the large works at Sheffield, he had observed that they were casting many ingots in the same manner as practised at Trubia, and that they were not using fluid compression. He had not seen there a single ingot intended for the manufacture of armour-plate which had been compressed in the fluid state. He had to offer the same observations in reply to Mr. Capron's remarks with regard to fluid compression. The only advantage derived from the operation was the greater economy of material, and it would be necessary to confirm, by means of practical experiments which would leave no room for doubt, the question as to whether any improvement in the physical and mechanical properties could be effected by liquid compression.

STEAM-ENGINES FOR DRIVING REVERSING ROLLING-MILLS.

BY JOHN W. HALL (BIRMINGHAM.)

A STEAM-ENGINE working a large reversing mill has to perform the most severe duty demanded of any engine.

To drive the rolls fast enough to finish long lengths at a single heat, the piston must run at the highest rate possible. To attain this speed promptly, there must be a sufficient reserve of power to impart to the crank-shaft immediately after starting a twist about twice as great as that needed to run the engines up to full speed, at which they will develop close upon 10,000 horse-power.

The engine must be under such perfect control that it can be kept creeping round until the rolls bite the piece to be treated; it must stop instantly when the piece leaves the rolls, and must reverse at once to take it back again; it must gather full speed so promptly that during the last few passes, when the section has become so thin as to cool rapidly, it can be got through the mill before it becomes so hard from loss of heat as to damage the rolls.

To ensure promptitude in starting, stopping, and reversing the revolving weights must be low and the steam pressure high, and yet the reciprocating masses must be light, or their weight will produce dangerous shocks.

The engines employed for the work usually have pistons of about 48 inches diameter, with a stroke of about 5 feet, and make about 120 revolutions per minute.

At the beginning of each stroke the reciprocating parts, consisting of the piston with its rod cross-head and connecting rod, by reason of their inertia, offer a great resistance to movement. The pressure must be high enough to overcome this, and to give them, in one-eighth of a second, a velocity of 31·4 feet per second, which gravity would need nearly a whole

second to impart, did they fall freely in space from a height of nearly 16 feet. The initial pressure necessary to do this is about 120 lbs. per square inch. The momentum imparted must then be absorbed, and the parts brought to rest in another one-eighth of a second, or a violent blow will be struck on the crank-pin and passed on to the crank-shaft bearings, wasting much power in mere destructive hammering of the brasses.

The slowing down is best effected by closing the exhaust port at a fairly early period of the stroke, so as to confine, between the rapidly advancing piston and the cylinder cover, as much as possible of the exhaust steam still remaining in the cylinder from the previous stroke. This is compressed into the port and clearance space, where it will replace an equal weight of live steam, which otherwise would have to be taken from the boiler. In this way the piston returns energy not utilised in overcoming the resistance of the mill, and stores it for use on its return stroke. The cushion of steam reduces the knock on the pin when the crank turns the centre, and if compression can be carried so far that the cushion pressure is as high as the boiler pressure, the whole of the surplus energy is recovered.

Now if the engine exhausts to the atmosphere the steam remaining in the cylinder may have a pressure of about 2·3 lbs. higher, or 17 lbs. absolute, which will rise in pressure to 68 lbs. when compressed into one-fourth of the space. But if the engine exhausts into a condenser the pressure remaining in the cylinder will be only about 2·3 lbs. above the vacuum in the condenser, or say 5 lbs. absolute; and when compressed into one-fourth of the space will rise in pressure only to 20 lbs. per square inch, which will provide a very poor cushion to bring the piston to rest.

Nor in this instance is the economy obtainable by using a condenser very great. The temperature of steam at a boiler pressure of 120 lbs.—say 135 lbs. absolute—is 350°, at 68 lbs. 300°, at 20 lbs. 228°. at 17 lbs. 220°, and at 5 lbs. 162° F. —absolute pressures in each case. Steam then entering the cylinder of an engine exhausting to the atmosphere finds the piston, cylinder cover, and port in contact with steam at a

temperature of 300° F., while no portion of the cylinder has been exposed to a temperature below 220° F.

But steam entering the cylinder of an engine exhausting into a condenser finds the piston, cylinder cover, and ports in contact with steam of only 228° F., while parts of the cylinder have been exposed to a temperature as low as 162° F.

In the case then of the condensing engine initial condensation will be considerably greater, and more steam must be taken from the boiler to fill the clearance spaces. Consequently a condenser, though increasing the power of such an engine, increases also the weight of steam used, so that the consumption per horse-power will not be much less, but the wear and tear will be much more.

To reduce the range of temperature compound engines are sometimes employed. Suppose that between the boiler and each 48-inch cylinder of a reversing engine we place a 30-inch cylinder, into which the steam from the boiler is first admitted. With the simple engine, at the moment of reversal, the full boiler-pressure can be thrown on to the 48-inch piston, which has an area of 1810 square inches, but with the compound engine this pressure can be thrown only on to the 30-inch piston, which has an area of only 707 square inches. Consequently the margin of power necessary for quick reversal is wanting. To ensure as prompt starting as in the case of the simple engine the cylinders would need to be nearer 40 and 64 inches in diameter, and this would nearly double the cost of the engine and its maintenance.

Methods are in use for banking up the steam in the receiver between the high- and low-pressure cylinders of a compound reversing engine for use at the moment of reversal, but such devices are not very effective. The economy of the compound over the simple reversing engine has not been very marked, and has been largely due to the fact that every time an engine is reversed a cylinder full of steam is thrown away. In a compound engine the steam from the low-pressure cylinder is wasted, but that from the high-pressure cylinder is caught and used up in the low pressure. When the steam can be used up in this way in a turbine the compound engine would

not seem to afford a saving of steam sufficient to justify its additional cost and complication.

While, therefore, it is not advisable to exhaust from a reversing engine direct to a condenser, the same objections do not apply to exhausting at about atmospheric pressure into a turbine, which can utilise this exhaust steam and itself discharge into a condenser, extracting from the exhaust steam about as much power as the engine has already got from the live steam.

This becomes possible because the heat in the steam is the cause for, and the measure of, its power to give out mechanical work, the energy from it being due and proportionate to the fall in temperature which occurs when steam is expanded in the engine, whether of the piston or turbine type.

Now steam at 120 lbs. boiler-pressure has a temperature of 350° F., and if rejected by the piston engine at just over atmospheric pressure, or 230° F., the engine cannot possibly convert into work more than 120° fall in temperature. If this steam is then passed through a turbine which can further expand it down to the temperature of the condenser, which is about 130° F., the turbine is then turning to account a further range of 100° , which otherwise would have to be wasted, because no piston engine can usefully expand steam much below five-sixths of atmospheric pressure. To do so the pistons would have to be of impracticable size and cost, while the friction caused by them, together with the loss of heat when such enormous surfaces were subjected to wide variations in temperature, would neutralise any gain theoretically obtainable by such high grades of expansion.

The turbine, on the other hand, has only one rotating part carried in two bearings, so that the mechanical friction is very low, the flow of steam through it is always in one direction, and therefore there are no losses induced by alternate heating and cooling; there are no clearance spaces to be filled up, there are no reciprocating pieces to set up inertia or momentum stresses, and therefore the speed of the blades is not limited to a maximum of 1900, but may reach over 19,000 feet per minute. This materially reduces the size and cost of the apparatus.

Still the turbine is not usually as efficient at high pressures as the piston engine. A well-fitted piston allows very little steam to pass it at any pressure, but the percentage of leakage through the clearance which must be left between the tips of the blades and the casing of a turbine is a serious matter at the high-pressure end, where the blades are short, though much less at the low-pressure end, where the blades are long and the pressure lower.

Hence the piston engine is most efficient at high pressures, but the turbine at those below the atmosphere, the combination comprising the best qualities of both types of prime mover. The exhaust turbine removes the only objection to the simple reversing engine, namely, its high steam consumption, but leaves its good qualities, its simplicity, and low first cost, and its amenability to prompt handling and rapid increase of speed all unimpaired.

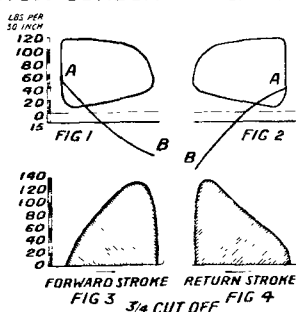
Figs. 1, 2, 5, 6, 9, 10, 13, 14, 17, 18, 21, and 22 are the indicator diagrams obtained from such an engine having a clearance space of 10 per cent. of the volume swept out by the piston—the smallest obtainable with piston valves—working with a pressure at the steam-chest of 120 lbs. above the atmosphere, and with the steam cut off at various points of the stroke. The mean speed of the piston is 1200 feet per minute, and the weight of the reciprocating parts $4\frac{1}{4}$ tons per cylinder—a fair average for such pieces. Figs. 1 to 10 are for the engine when non-condensing, and Figs. 13 to 22 when condensing.

To allow for the influence of the inertia and momentum of the reciprocating parts the lines A B are drawn across each diagram; they are curved to allow for the irregularities in velocity introduced by a connecting rod of the common length—five times that of the crank.

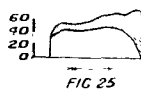
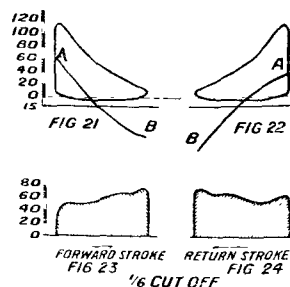
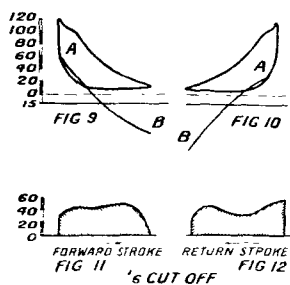
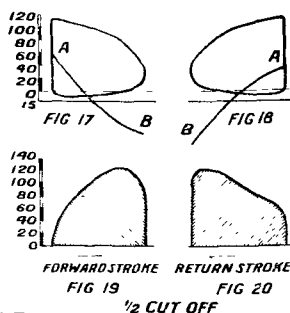
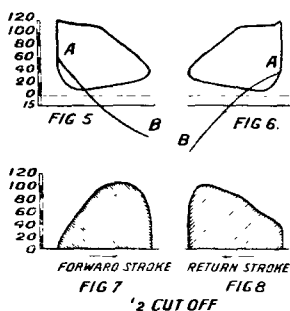
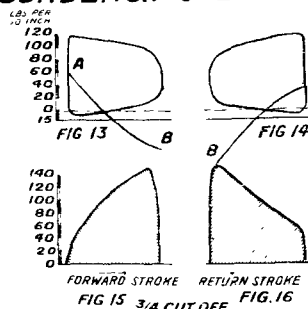
By taking the difference of pressures shown by the indicator to exist on the two sides of the piston, and deducting from this the height of the inertia curve when above, and adding the depth when below the line, there are obtained the diagrams Figs. 3, 4, 7, 8, 11, 12, 15, 16, 19, 20, 23, and 24, shown cross-hatched below each indicator diagram.

These "equivalent pressure" diagrams are most convenient.

NON-CONDENSING ENGINES



CONDENSING ENGINES



On them the resistance induced by inertia is subtracted from, and the assistance induced by momentum is added to, the force produced by the steam. Then by multiplying the "equivalent pressure" answering to any point in the piston's travel by the effective leverage of the crank at the same instant, the tangential twist actually exerted on the crank shaft is accurately known, whatever may be the position of the crank.

The above method is doubtless familiar to all making a serious study of the steam-engine, but it may be as well to point out how clearly this graphic method proves that the condenser, by reducing the pressure of the exhaust steam, impairs the cushion required to bring the piston and its attached parts quietly to rest. In Figs. 25 and 26 the equivalent diagrams for a cut-off at one-sixth of the stroke when non-condensing are superposed on the diagram when condensing, and the difference between them is cross-hatched. Instead of the pressure upon the crank-pin decreasing, it increases towards the end of the stroke, more particularly on the return stroke, in which, owing to the angle of the connecting rod, the speed of the piston is greater during the fourth than it was during the third quadrant traversed by the crank-pin. The motion of the piston of an engine exhausting into a condenser is that of the foot of a cyclist who stamps on his pedals instead of reducing the pressure as his foot nears the bottom of the stroke.

The earlier in reason the steam can be cut off the less of it will the engine use. But if the valve gear is so arranged that steam cannot be carried very far in the stroke, there must be many positions in which, when the engine is stopped, steam admitted to the steam-chest cannot find its way into the cylinder because the valves block the ports; or, if the steam can get in, the position of the crank is such that there is not sufficient purchase to turn the shaft round.

The case of an engine having two cranks set at an angle of 90° from each other is shown in Fig. 27. The upper part exhibits the effort which the steam can exert on the crank to start the engine from the state of rest in any position, with valves set to cut off at a maximum period of three-

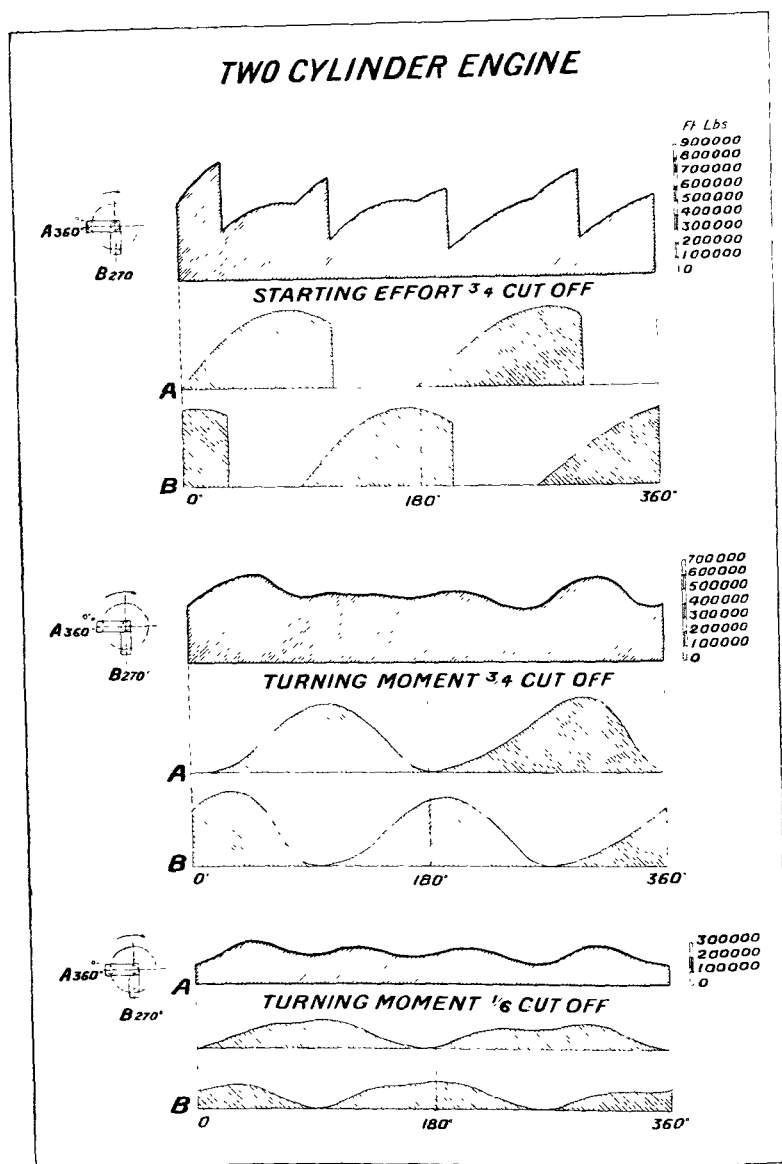


FIG. 27.

quarters of the stroke. In practice this is found the earliest point in the travel of the piston to which it is possible to limit the admission in an engine with only two cylinders, if such an engine is to start promptly. This allows a minimum starting effort of 190,000 foot-pounds in any position in which the engine may chance to stand.

Fig. 28 shows that if a third cylinder be added, and the cranks are spaced at an angle of 120° apart, the valves may then be set to limit the admission to half stroke, and yet there will be an effort of 190,000 foot-pounds available for starting the engine. The saving in steam due to limiting the maximum cut off to half instead of to three-quarters of the stroke will be about 30 per cent. at the latest cut off, when the consumption of steam is highest.

The turning moment of the three-cylinder engine when running is also much improved. At high speeds, when shocks are most detrimental, the variation between the maximum and the minimum turning efforts is as 2.2 is to 1 in the two-cylinder, but only as 1.5 is to 1 in the three-cylinder type. The running at slow speeds is also better, because the weight of the three cranks balance each other in any position, and there is none of that tendency to "hang" displayed by two-cylinder engines when both cranks come to the bottom.

With two cranks at right angles the centre of gravity of the cranks, pins, and connecting rods is situated at a considerable distance outside the axis of the crank shaft; at high speeds this sets up a large unbalanced force tending to move the engine as a whole upon its foundations, which must be massive to absorb the vibration. With three cranks spaced equally there is no such unbalanced force tending to move the engine as a whole.

True, both these defects of the two-cylinder engine can be counteracted by balance weights, but as these add considerably to the revolving weights, they make the engine more sluggish in starting and less prompt in stopping.

From every point of view, then, the three-cylinder engine is superior to the two-cylinder, and its very general adoption of recent years is not therefore surprising.

THREE CYLINDER ENGINE

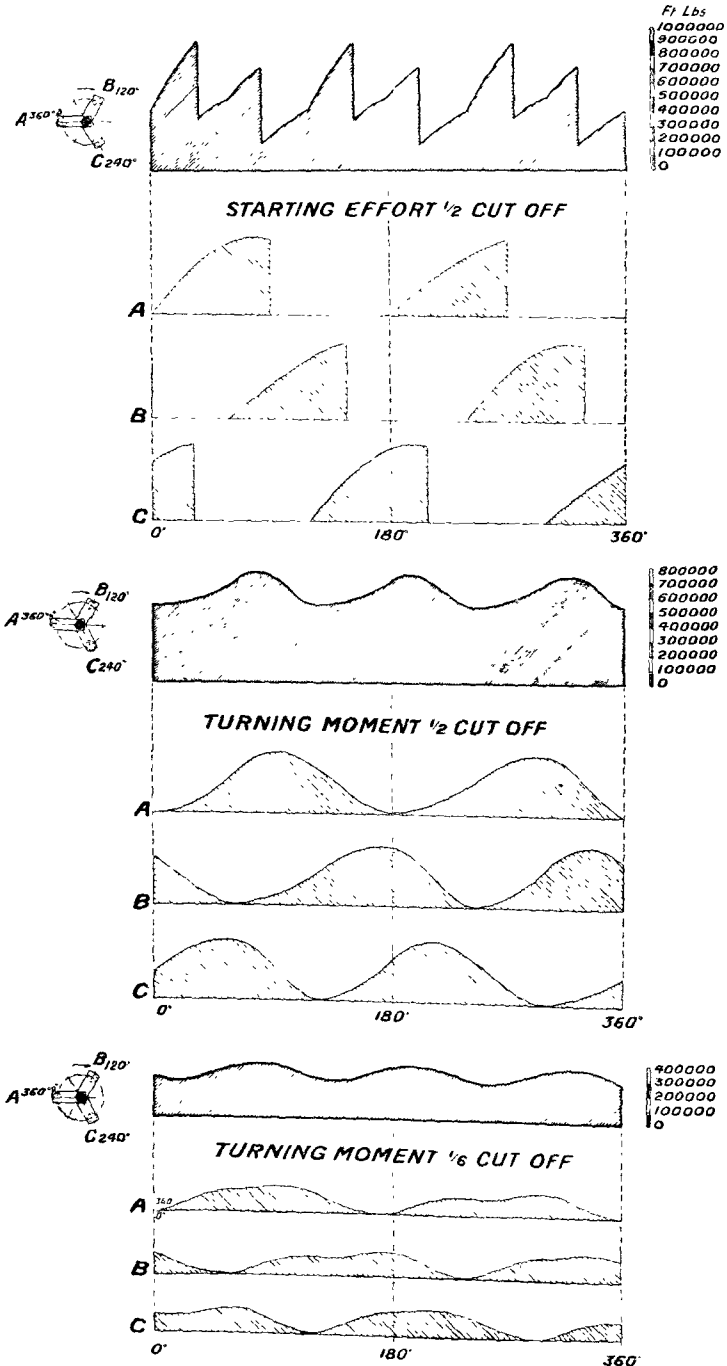


FIG. 28.

Reversing engines, which are none too large to start quickly, all have such an excess of power when at full speed that, though the valve gear is linked up, the engines run away unless the steam is throttled down from boiler pressure, involving considerable loss by "wire drawing."

On considering the defects of existing reversing engines it occurred to the writer that by still further multiplying the number of cylinders and reducing their capacity, the starting effort could be increased and the full boiler pressure utilised much later in the run, with a saving of steam both at commencement and finish.

Fig. 29 shows the working of an engine having five cylinders 36 inches diameter by 36 inches stroke, the combined capacity of which is 44 per cent. less than that of three cylinders 48 inches diameter by 60 inches stroke, and 15 per cent. less than that of the two-cylinder engine of that size. Yet the minimum starting effort of the five-cylinder engine is 42 per cent. greater than that of the three, and 37 per cent. greater than that of the two-cylinder engines with larger cylinders.

But apart from the saving in steam which this would effect the shorter stroke of the five-cylinder engine would permit of its being run at 200 revolutions, without exceeding the piston speed of the larger engines, running at 120 revolutions, so enabling a larger output to be obtained from the mill.

Also the turning moment obtained from the five-cylinder engine, as shown in Fig. 29, is so nearly constant that the maximum stress on the crank-shaft, the spindles, and rolls is 25 per cent. less than with the two-cylinder, and 29 per cent. lower than with the three-cylinder engines.

The cranks also balance each other against gravity in any position, just as in the case of a three-cylinder engine; so that there are no unbalanced forces tending to move the engine as a whole on its foundations, and the local unbalanced force may be materially reduced. By placing the two adjoining cranks, not at 72° apart but at 144° , the weights concentrated at the crank-pins go a long way towards balancing each other, the disturbing couple being situated at a distance of only 5.56 inches from the centre of the crank-shaft, whereas in the three-cylinder engine the couple tending to shake the bearing

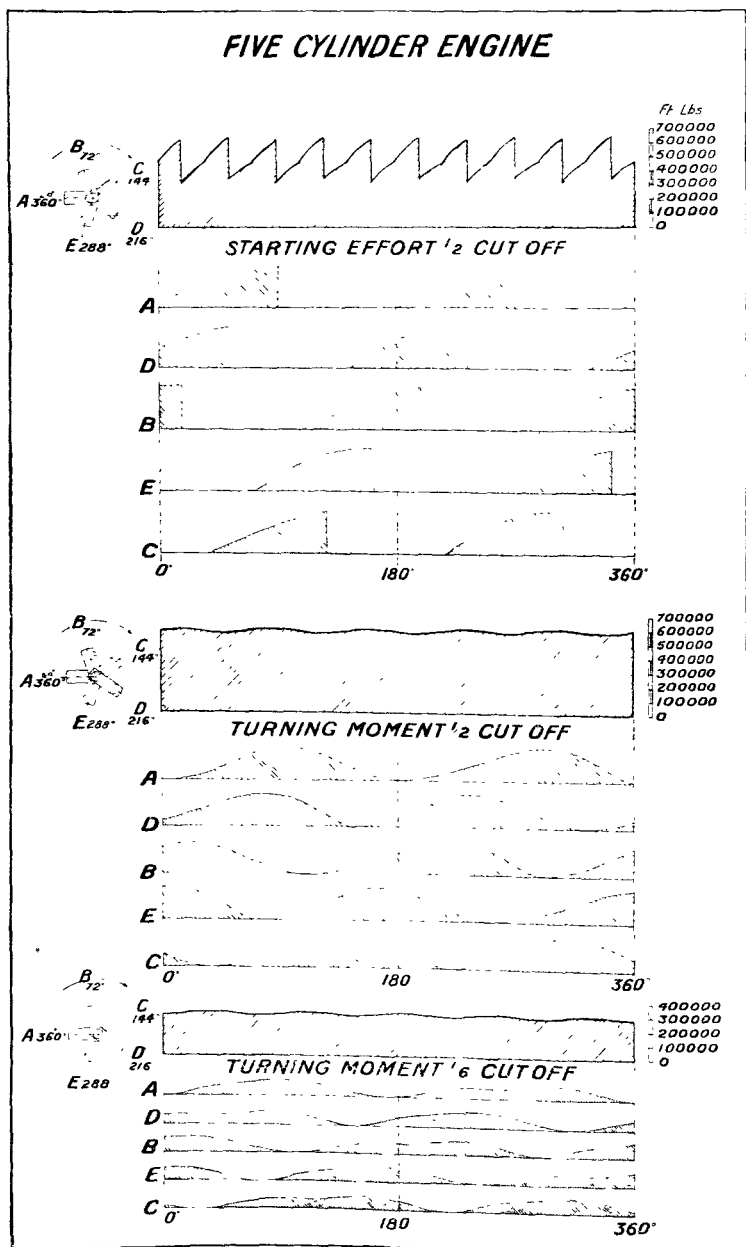


FIG. 29.

between the two cranks will be situated at 15 inches from the axis of the shaft; and as the centrifugal force is proportional to the square of the speed, the disturbing force, at the same number of revolutions, with the five-cylinder engine will be as 31 is to 225 in the case of the three-cylinder engine—only about one-seventh as great—supposing the weights for both engines were alike, whereas the connecting rods of the five-cylinder would be appreciably lighter.

In addition to these advantages, the first cost of five engines with cylinders 36 inches diameter by 3 feet stroke would not be more than about three-fourths of that of three engines having cylinders 48 inches diameter by 5 feet stroke.

The cost of the spare parts to be kept in stock in case of a breakdown would also be reduced by about one-half; and if the five sections of the crank-shaft were made all precisely alike, as could be easily arranged, only one-fifth of a crank-shaft would be needed to insure immunity against having to wait while a new crank-shaft was being made to replace a broken one. Indeed there would probably be very little difficulty in running with four cylinders only for some considerable period if desired.

The most marked advantage, however, would be in the case of a plant containing cogging, roughing, and finishing mills. In this case the keeping in stock of a complete spare engine, even down to the cylinder and bed-plate to renew any one broken, would only add one-fifteenth to the whole cost of the three sets of engines, and by making the parts interchangeable a damaged engine could be literally lifted out and a new one dropped in its place without stopping the plant for more than a few days.

There is one further point to deal with, namely, the steam pressure.

The higher the pressure against which the engine exhausts the more efficient is the cushion. There seems no reason why the common pressure of 120 lbs. should not be materially increased now water-tube boilers are available. The writer has had several engines, for the design of which he is responsible, working for some years now with steam of 200 lbs. pressure superheated 150° F., and has experienced no trouble

whatever with them. Pressures of 250 and 265 lbs. have long been common in the navy; and there seems no reason whatever why steam of 300 lbs. pressure, superheated 150° F., up to which temperature no difficulties arise, should not be regularly used in reversing engines.

Fig. 30 shows the theoretical diagrams worked out for a reversing engine with a clearance space of 15 per cent., starting with a boiler pressure of 300 lbs. and exhausting against a pressure of 80 lbs.; then, allowing for a loss of 15 per cent. in transfer, this steam is shown expanded down in an engine having a clearance space of 10 per cent. (easily obtainable when engines are not required to reverse) expanded three

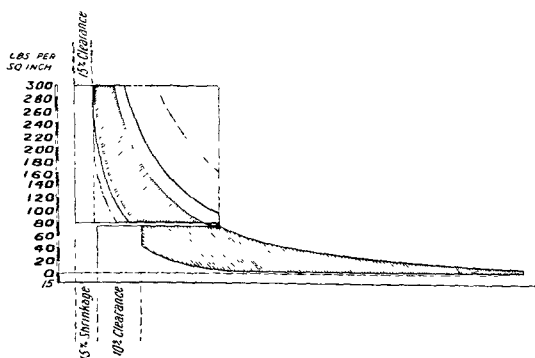


FIG. 30.

and one-half fold, and exhausted at 17.5 lbs. absolute, after which it would be expanded down again in an exhaust turbine.

Consider the case of blast-furnaces consuming 50 tons of coke per hour and yielding 140,000 cubic feet of gas per ton of coke; the gas given would be 7,000,000 cubic feet. Allowing 45 per cent. of this for heating the stoves there would remain for producing power 3,850,000 cubic feet of gas per hour. Employing this gas to raise steam at 300 lbs. pressure, superheated 150° F. in boilers capable of evaporating 50 lbs. of water per 1000 feet of gas, there would be available 192,500 lbs. of steam per hour.

This steam taken direct to reversing engines in the mill,

requiring 30 lbs. of steam per indicated horse-power when exhausting against a pressure of 80 lbs. per square inch, would afford a continuous output of 6416 indicated horse-power hours.

Allowing that this exhaust steam would lose 15 per cent. in weight by condensation, &c., and drop 5 lbs. in pressure, there would be left 163,625 lbs. of steam at 75 lbs. pressure to supply blast. Engines worked by this steam, which would yield one indicated horse-power for every 31 lbs. of steam when discharging at a little above atmospheric pressure, would provide 5278 indicated horse-power for blowing the blast-furnaces. The blast required would be about 4,875,000 cubic feet per hour, or 81,250 cubic feet of free air per minute, to compress which to 8 lbs. pressure per square inch would require about $32\frac{1}{2}$ nett indicated horse-power per 100 cubic feet, or 2641 indicated horse-power. Blowing-engines having a mechanical efficiency of 85 per cent. and a volumetric efficiency of 90 per cent. (giving an over all efficiency of $76\frac{1}{2}$ per cent.) would absorb in this work 3452 indicated horse-power, leaving a margin of 1826 indicated horse-power to meet contingencies.

Deducting 5 per cent. leaves 155,444 lbs. of exhaust steam from these engines, which would produce, in an exhaust turbine capable of generating one electrical horse-power for 30 lbs. of steam 5181 electrical horse-power for the supply of current for the various purposes for which power is required about a works.

Seeing there would be only one set of boilers and one set of condensing plant for the three departments—the blast-furnaces, rolling-mills, and general electric supply—while all the engines would be of simple pattern, the first cost of such plant would be extremely moderate and the working costs very low.

It may be interesting to compare this proposed method of working with that of doing the same work by gas-engines, taking 1000 cubic feet of gas to produce $11\frac{1}{2}$ indicated horse-power. The gas-blowing engines, to be capable of producing the same power as before, namely 5278 indicated horse-power, would require 458,956 cubic feet of gas; to provide electric current equal to 5181 horse-power would require 7200 indi-

cated horse-power, consuming 626,087 cubic feet of gas; and taking the over all efficiency of an Ilgner set at full load at 60 per cent., or say 55 per cent. average, there would be required 11,665 indicated horse-power to drive the mills, consuming a further 1,014,434 feet of gas, making in all a total of 2,099,479 cubic feet. This would leave a surplus of 1,750,521 feet of gas available for some other purpose.

Against this, however, would have to be set the interest, depreciation, and wear and tear of the gas-cleaning and electric plant and gas-engines, and the higher amount of wages necessary to clean, work, and tend them.

Which of the two systems would, on the whole, be the cheaper to run would depend upon the price obtainable for the surplus power.

DISCUSSION.

Mr. A. LAMBERTON, Member of Council, said he thought the author had made out quite a good case for his proposal to use multiple-cylinder high-pressure engines in combination with low-pressure turbines, but it was well to bear in mind that all such matters had to be considered on their individual merits, and he could conceive many cases where it would not be the best arrangement to use an uneconomical engine as the prime mover with a view to obtaining a higher economy at a later stage. In many cases he thought it might prove to be the truer economy to use compound condensing engines as the prime mover, and develop no more power than that required to drive the mill. If, however, the circumstances were such that in an installation such as proposed by the author the whole power recovered in the exhaust steam-turbine could be profitably used in the works, the total efficiency of such a plant would be very satisfactory indeed.

With regard to the author's proposal to use high-pressure engines having five cylinders, instead of the usual two or three cylinders, the advantages claimed for that arrangement were undoubtedly considerable, notably in regard to the limiting of the variations in the torque diagram, whilst at the same time giving an improved starting torque. He could not, however, agree with the author that the cost of such a five-cylinder engine would not be more than three-fourths of a two or three cylinder engine of the same starting power, because, although the total weight might be somewhat reduced, the total amount of work would be very considerably greater; but this was a matter that could only be determined by making a design, and carefully estimating the weights and work entering into such. Apart from that, he had some doubts as to whether the author was attacking the problem at the right end. The great advance which had taken place in steam engineering during the last few years—particularly in regard to compound steam-turbines working with superheated steam, in which the highest efficiency yet recorded in steam prime movers had been realised—suggested that the use of such turbines as the prime mover would be the ideal way of attacking the problem if reversing of the mill could be satisfactorily accomplished. There had been various arrangements designed for effecting that reversing of the mills whilst using a high-efficiency continuous-running motor, and one of the most interesting which he had a knowledge of was that proposed by Dr. Föttinger, termed the "Hydraulic Transmitter." Broadly speaking, that gear consists of:—

(1) A high-efficiency centrifugal pump driven from the prime mover shaft; and

(2) A water-turbine fixed to the shaft to be driven.

The power water from the centrifugal pump was directed against the vanes of the water-turbine, and the connection between the prime mover and the driven shaft was therefore purely an hydraulic connection. When the driven shaft required to be reversed, that was accom-

plished by a suitable valve turning the power water on to a second set of vanes set at the opposite angle, and motion in the other direction was thus produced; and that reversing of the direction of rotation was accomplished very quickly and without shock.

It might not be known to members of the Institute that that hydraulic transmitter had been at work on board steamers for the last two years, and an efficiency of 85 per cent. had been steadily got from the apparatus. That was a very good result to be got by practically the first installation that had been made, and seemed to justify the hope that higher efficiencies would yet be realised when the improvements that experience suggested had been made.

If such an apparatus as that could be successfully applied to reversing rolling-mills, it would lead to great economy in enabling continuous-running prime movers of the highest efficiency to be used; but that was a matter that was not yet determined, although the inventor had good hope that he would succeed in that. The driving of a reversing rolling-mill, however, was a very different problem from that which was involved in marine work, because the highest starting torque was called for whilst the mill was at rest; and it would be interesting to see how Dr. Föttinger would succeed in handling that problem, and what efficiencies his apparatus would realise under those conditions.

In conclusion, he congratulated the author upon the very interesting and valuable paper he had submitted.

Mr. A. J. CAPRON (Sheffield) said that he only wished to raise one point, and that was with regard to the comparison between the three-cylinder and the five-cylinder engine. The comparison made by the author did not seem to be quite a fair one, as the average turning moment of the five-cylinder engine was very low compared with the three-cylinder engine, the minimum starting moment being about the same in both cases.

Mr. J. H. HARRISON (Middlesbrough) thought that the proposal to multiply the cylinders of the rolling-mill engine was hardly in the right direction, as it also multiplied all the moving and wearing parts, and led to the suggestion that there would be more upkeep and more wear and tear of various kinds. It would in the long run militate against the idea of using five cylinders instead of three. Quite apart from that, there was the question of taking up greater space, and space in rolling-mills was not often available. Mr. Lamberton had questioned Mr. Hall's remarks that a five-cylinder engine of similar power would cost less than a three-cylinder, and but for the fact that presumably Mr. Hall had gone into the matter, he was surprised that the comparison was so good. The author also mentioned in the paper an example of using steam at high pressure in these five-cylinder engines. He saw no real objection to steam at 300 lbs. and superheated 150°. That should be just as feasible and possible in a rolling-mill engine as in a marine engine, but he was not sure that

it was possible to get the same class of attention in a rolling-mill engine that would be given to engines which were more directly under the supervision of men of high calibre. The author also spoke of evaporating 50 lbs. of water per 1000 cubic feet of gas, but he hardly thought he would get as much as that. That, however, did not concern the question very much. The author also spoke of generating in exhaust steam-turbines with 30 lbs. of steam per electrical horse-power. He did not mean to criticise the figures too much, but he wished to infer that Mr. Hall had taken rather optimistic figures in the example he had given. Apart from that it meant that they must have entirely new engines for the rolling-mill, and it was not often they had an opportunity of putting in such engines. More often it was a matter of putting in new engines upon ground already occupied by others of smaller size, and in that event they would be at a disadvantage in the case of mills at present working. It was no use spending money on large new engines and plants unless there was some market for the surplus output of electric power. If there was no market for that there was no need to go to great expense to get it.

MR. WALTER DIXON (Glasgow) said it had hitherto been considered that the only practical method of dealing with exhaust steam was that of passing it through a turbine, for, as the author had said: "No piston engine can usefully expand steam much below five-sixths of atmospheric pressure. To do so the pistons would have to be of impracticable size and cost, while the friction caused by them, together with the loss of heat when such enormous surfaces were subjected to wide variations in temperature, would neutralise any gain theoretically obtainable by such high grades of expansion." He thought it would be interesting to those present to know that such a statement, though generally accepted, was not universally accepted, and that there were at present at work on the Continent several horizontal piston engines of over 1000 horse-power running on exhaust steam, and that such engines had been built by an important engineering firm for important works, and the claim had been made that on the score of economy and first-cost, such engines compared favourably with the turbine.

MR. A. GREINER, Vice-President, said he would like the inventor of the Föttinger apparatus to give the Institute some details about it, as it undoubtedly had a great future before it. His firm (Cockerill at Seraing) was building at present a boat with two Diesel oil-engines of 600 horse-power each. They were to be run at 340 to 360 revolutions per minute, which was too much for the screws. The screws were to run at from 60 to 75, and never more than 90 revolutions per minute. The Föttinger apparatus was placed between the oil-engines and the screws, and experiments carried out at the Vulcan Works at Stettin, under the supervision of Mr. Föttinger, had proved that the loss of power between the motor and the screw was not more than 15 per cent.

This was a very good result, when the increased facility which the apparatus gave in stopping and reversing was taken into account. There was only one controlling lever, and the apparatus enabled the Diesel engines to be run at a constant speed of about 340 revolutions per minute, while the screw could go slowly or quickly according to needs. The ship was not yet finished, but, judging from the experiments he had witnessed at Stettin, he did not see why the Föttinger system could not be used successfully for rolling-mill work, in connection with reversing engines.

More than thirty-five years ago he made the acquaintance of Mr. Menelaus at the moment when he was changing his beam-engines at Dowlais, because he found they were not running fast enough to roll rails of the great lengths which were required at the time, and the difficulty was how to replace those old-fashioned beam-engines by reversing ones. He (Mr. Greiner) came to England with one of his foremen, and saw that everywhere the same type of geared engine was in use. He believed it was the original type of reversing engine designed by Ramsbottom. When he came to Dowlais he asked how they proposed to alter the engine there. They would not tell him, but when they left the works his foreman and he came to the conclusion that there was no reason why a mill should not be driven direct from the steam cylinders, just as a locomotive or a paddle-ship was, and they knew that in the neighbourhood of Dowlais there was a works in which rolling was done by means of an old engine with two inclined cylinders, taken out of a steamship. They did not see that engine, but went home with the idea that what was possible in ships should also be possible for rolling-mills, if they could give sufficient strength to the crank-shaft, the calculations of which was scarcely understood at the time. However, they succeeded, and the first engine they built gave very good results. Since then they had built many reversing engines for other manufacturers. He did not see why, if engines in ships could be controlled by such an apparatus as the Föttinger transformer, that apparatus could not also be used in the case of rolling-mills.

Mr. T. C. HUTCHINSON (Skinningrove) said some reference had been made to boiler efficiency, because steam efficiency was dependent on boiler efficiency. With regard to the boiler which was the invention of Professor Bone, the author might be interested to know that at the works he was connected with at Skinningrove they had one of Professor Bone's boilers, which was capable of evaporating 500 gallons per hour. They had had very careful measurement of the gas consumption, and they found that there was an efficiency of 95 per cent. of the gas consumed. They used a small proportion of the steam to drive a fan. The boiler, which had a diameter of 10 feet with tubes only 3 feet long, was in constant work. His firm would be very glad to show anybody who was interested in the boiler its method of operation. By means of a meter they ascertained the amount of gas consumed by the boiler. This gas was obtained from coke-ovens, and

the calculation had been very carefully made. He had seen the measurements of gas for the experimental boiler supplied with gas from a general supply, and the efficiency of the smaller boiler very closely approximated to that of the larger boiler.

The PRESIDENT, in moving a vote of thanks to the author, said that was not a paper which could be discussed hurriedly, and he hoped that members would contribute their views in writing. The remarks by Mr. Lamberton raised a very important question with regard to the application of power, and it would be very interesting indeed if Dr. Föttinger could be induced to submit a paper to be read at the next meeting. He trusted that Mr. Lamberton would do what he could to bring about that result; they would be very much obliged to him if he would do so. He was sure they would agree with him in tendering their best thanks to Mr. Hall for his paper; at the same time the best thanks of the meeting were also due to Mr. Hutchinson for his kind offer to give members an opportunity of seeing the Bone boiler in operation. Mr. Hutchinson had been good enough to allow him to see the boiler, and he felt sure that members would be very greatly interested if they accepted that gentleman's invitation.

CORRESPONDENCE.

Mr. HALL, in replying on the discussion, wrote that Mr. Lamberton had put the matter in a nutshell when he said that every case required to be considered on its own merits. He (Mr. Hall) did not pretend that his suggestion was of the nature of a patent pill guaranteed to cure all the troubles in a steelworks, or to fit in with every possible and conceivable condition. He had simply brought it forward as one method, which he thought was worth considering, and whether he had made out his case or not was a question which he would leave to the members to determine. Mr. Lamberton had mentioned the Föttinger system of hydraulic transmission. But if hydraulic transmission was to be adopted, why use an engine at all? He (Mr. Hall) thought that one of the most promising schemes, and one which was being experimented with on the Continent, namely using the Humphrey pump, with which many of the members were familiar, was far simpler. It was an explosive gas pump, delivering water under a high pressure, which could be employed to drive reversing turbines. The advantage of that arrangement over an ordinary gas-engine was obvious, as there would be no pistons to cause trouble, and there should be no necessity for cleaning the gas, because the valves could be washed by the water at every stroke. He had an idea that that system of generating and transmitting power had a great future before it. He would have been interested to hear more about it, and regretted that the gentleman who could have given them the information

on the matter was not present. With regard to the question of the average turning moment, it was quite true that the five-cylinder engine would not have the same average turning moment as the three-cylinder, but against that disadvantage had to be set the fact that there would be an excess of power. The real difficulty with a reversing engine arose in connection with the starting moment, and the sluggishness with which the engine got up speed. It was the minimum, not the mean turning moment, that determined the start. When the engine was once started there was always an excess of power, and the engine should be so arranged as to secure its power at the earliest moment: they always had more than enough power towards the end of the run, and had to throttle down the steam by hand. True they had five engines to look after instead of three, but they were smaller. What about the six-cylinder engines which Mr. Greiner and others on the Continent used, having three high-pressure cylinders with three low-pressure cylinders behind them? If those were justifiable, surely those he (the author) proposed were. It did not follow that the smaller and more numerous parts would cost more to repair than they would if fewer and larger. In any case it was a question of balancing advantages and disadvantages, and that applied to all such cases. The difficulty of getting the engine into a confined space was of course real, but in many cases that would not be serious, for though the five-cylinder engine would take up a greater length along the crank-shaft than the two-cylinder, it required less space in the other direction. There was not a great deal of difference either way in that respect. Mr. Dixon had mentioned the use of piston engines worked with steam exhausted at about atmospheric pressure from other engines. He was rather surprised to hear that that had been done successfully, and if they would follow his figures he thought they would agree with him that it was a little surprising. The available pressure was only 15 lbs.: the back pressure could hardly be less than 3 lbs., which would make the net available pressure for driving the mills 12 lbs. They could not rely upon getting a diagram factor of more than 80 per cent., and that would bring down the working pressure to an equivalent of about 9 lbs. effective pressure. They would have to deduct something for the friction of the engine, and he did not think there would be more than 7 lbs. actual effective pressure remaining out of the 15 lbs., which was the original amount supplied from the high-pressure engines. Looking at those facts, and at the very high cost of such plant, he did not think that such scheme could be justified, unless there were advantages which were not at present apparent. The engine described by Mr. Greiner was probably the Panteg engine. It was designed by Mr. Scott Rawlings, and was constructed with two diagonal cylinders, and so far from coming out of a steamship, it was in fact expressly designed for the place where it worked. Mr. Hutchinson's statement as to the Bone boiler was most interesting, and if they could obtain an efficiency of 95 per cent., that would certainly make a difference. Personally he was not prepared to state what was the exact efficiency of a gas-fired boiler, but

he thought it was in the neighbourhood of 65 to 70 per cent. They could not get a closer efficiency than 80 per cent. with the best boilers fitted with economisers as compared with 95 per cent. with the Bone boiler. It was very interesting to learn that 95 per cent. efficiency had been obtained, and he hoped that they would hear more about it. He was very much obliged to them for the way they had received the paper.

THE INFLUENCE OF HEAT ON HARDENED TOOL STEELS

WITH SPECIAL REFERENCE TO THE HEAT
GENERATED IN CUTTING OPERATIONS.

By EDWARD G. HERBERT, B.Sc. LOND.

BEFORE describing the experiments which are to form the subject of this paper, it is necessary briefly to refer to certain previous investigations made by the author, which were fully described in a paper read before the Iron and Steel Institute in May 1910.¹ The subject of these investigations was "The Cutting Properties of Tool Steel," and they were carried out with the aid of the tool steel testing machine. This machine has been described both in the paper referred to and in the technical press. Suffice it here to say that the machine measures the durability of specimens of tool steel, which are made into cutting tools of standard shape, and tested by being caused to cut away, by a turning action, a revolving steel tube of standard composition, hardness, and dimensions. The standard traverse of the tool is 0.012 inch per revolution of the tube, and the width of the chip is $\frac{1}{16}$ inch, this being the thickness of the tube wall. The durability of the tool is measured by the length of tube it will turn away before attaining a measured degree of bluntness. Tests are made at a succession of cutting speeds from 20 feet per minute upwards, and the results are plotted out in the form of a "speed curve," in which ordinates represent durability of the tool and abscissæ the corresponding cutting speeds.

A set of speed curves is shown in Fig. 1. These curves exhibit the changes in the durability of a carbon steel, made dead hard and tempered for fifteen minutes at various temperatures indicated on the diagrams.

The general characteristics of these curves are:—A very

¹ *Journal of the Iron and Steel Institute*, 1910, No. I. p. 206.

low durability at the lower cutting speeds; an increase of durability as the cutting speed increased; a maximum durability at cutting speeds of 50 to 80 feet per minute; and a decline of durability to a very low value as the speed was further increased.

Two of the curves, taken from tools tempered at 130° C. and 140° C. respectively, show two maxima with a depression between them.

These general characteristics are common to the speed curves of all the tool steels that have been tested, whether of the carbon, tungsten, or tungsten-vanadium varieties. All are capable of giving either single or double-peaked curves, according to the heat treatment they have received, and all show a low durability at low cutting speeds, this characteristic being especially marked in the case of some high-speed steels, which latter often retain their durability at very high speeds.

In the paper referred to, the theory was put forward that the observed changes in the durability of cutting tools are mainly caused by changes in the temperature of the cutting edge, due to varying quantities of heat generated at different cutting speeds.

The heat theory was confirmed by experiments showing that changes of durability corresponding to those which occur under varying cutting speeds, can be produced by varying the temperature of the tool in other ways while the cutting speed remains constant, viz., by varying the temperature of the water with which the tool is flooded; by varying the depth of cut (a heavy cut generating more heat than a light one), or by dispensing with the cooling water. It was shown also that the results of Mr. F. W. Taylor's classical experiments with cutting tools are in strict conformity with the "cube law of cutting speeds" deduced by the present writer from a theoretical consideration of the heat generated in cutting. The cube law is thus expressed: "For constant durability of the cutting tool the speed varies inversely as the cube root of the product of area of cut by thickness of shaving."

So much by way of introduction. In the present paper the heat theory of durability will be taken as experimentally established, and an attempt will be made to connect the

observed changes in the cutting durability of tool steels with changes in the physical properties of the steels as shown by breaking tests made at various temperatures.

The various problems that are to be dealt with may be clearly stated as follows:—

A. It has been found by experiments on the tool steel testing machine that all tool steels, without exception, have a very low durability, and are very quickly blunted when cutting under water at low speeds and fine cuts, under conditions, that is to say, which preclude any considerable heating of the cutting edge; and it has been found that any alteration in the cutting conditions which tends to increase the temperature of the cutting edge, results in an increased durability of the tool. What, if any, are the correlative changes in the physical properties (strength, hardness, toughness, &c.) of hardened steel which occur when it is raised from a low to a higher temperature?

B. All varieties of tool steel have been found to be capable, when suitably hardened, of producing double-peaked speed-durability curves, the characteristics of such steels being that at a certain speed they are less durable than at higher and lower speeds. Is it possible to correlate this low durability at a certain speed with a particular physical condition at a certain temperature?

C. All tool steels are found to lose their durability when the cutting speed is raised above a certain limit. Is there any corresponding change in their physical properties when they are heated above a certain temperature?

D. Assuming that each cutting speed corresponds to a definite temperature of the cutting edge (the weight of cut and all other conditions remaining constant), what are the actual temperatures of the cutting edge corresponding to the various cutting speeds, and corresponding to the various changes in the durability and physical properties of the steel?

Before dealing with these problems, it is necessary briefly to consider the nature of the actions tending to wear or blunt a cutting tool, and the correlative physical properties constituting durability, which the tool must possess in order to withstand these actions.

The principal action to which a tool is subjected in cutting is one of friction under heavy pressure. This tends to rub the surface of the steel away, by causing the particles of steel to slide over one another. To resist blunting by this action a tool must possess hardness.

But the stress on the tool point is not constant : as the chip is detached it breaks up into a series of short segments (more or less completely separated), and this process subjects the tool to a succession of changes of pressure, amounting almost to blows, and tending to chip off portions of the cutting edge. To withstand this action the tool must possess toughness.

If a tool of glass and another of copper be made, and used to turn a cylinder of soft material such as lead in the lathe, it will be found that both are very soon blunted, but from totally different causes. The glass tool, though extremely hard, is brittle, and is blunted by the chipping away of minute particles of the cutting edge. The copper tool, though very tough, is soft, and is blunted by the rubbing away of the cutting edge.

If now by some subtle alchemy it were possible gradually to change the tool of glass into one of copper, it would probably pass through some intermediate stages where it would retain some of the hardness of glass without all its brittleness, and would have attained to some of the toughness of copper without all its softness. The tool in this intermediate state would probably keep its sharp cutting edge much better than either the glass or the copper tool. A diagram showing the durability of such a tool in its successive stages would be likely to take the form of some of the curves in Fig. 1, the durability rising to a maximum as the tool lost its brittleness, and then falling to a low value as it lost its hardness.

In order then to measure, throughout a range of temperatures, those physical properties of a steel which constitute its durability, it is necessary to test it at each temperature for hardness and for toughness.

The usual method of testing toughness is that of the impact pendulum. Some preliminary experiments were made by this method, but it was found that whereas one specimen might be shattered with an absorption of the energy of the pendulum

so slight as to be difficult of measurement, another specimen only slightly different in temper would absorb the whole of the energy of a heavy pendulum without being bent or broken. It became evident that a shattering blow bears so little resemblance to the stress to which a cutting tool is subjected as to afford very little useful information relative to durability.

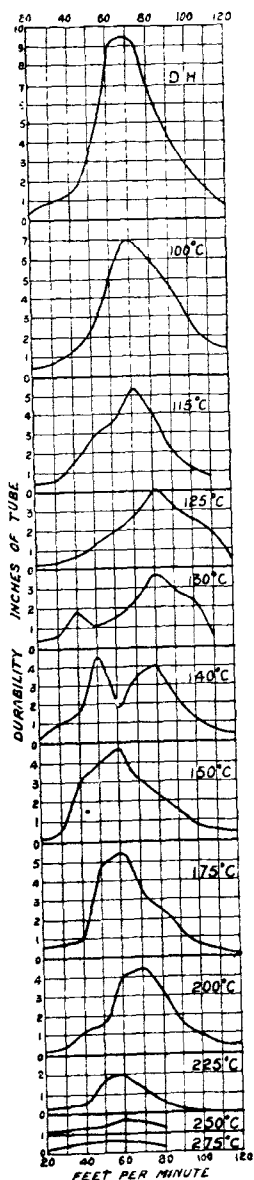


FIG. 1.—Temper and Durability. Carbon Steel.

The method finally adopted was that of breaking the specimen, supported at the ends on knife edges, by a load applied transversely at the centre. The apparatus employed is illustrated in Fig. 2. The specimen A was in all cases 3 inches long, $\frac{1}{4}$ inch deep, and $\frac{1}{2}$ inch wide. It was supported on knife edges BB, $2\frac{1}{2}$ inches apart. A third knife edge C was affixed to a plate F, and guided by pins DD sliding freely in holes in F. The whole was placed in a bath containing water, oil, or salt, according to the temperature under investigation, the specimen being completely immersed in the liquid. The bath was rested on iron blocks GG, with gas-burners or blow-pipes between them, and the whole was placed under the crosshead of the Olsen 100,000 pounds autographic testing machine.

In operation the bath was first heated, and the temperature (measured by a mercury thermometer) allowed to become stationary. The specimen was placed on the knife edges, and five minutes were allowed for it to arrive at the temperature of the bath. The load was then applied, and the specimen broken or bent. The load and the deflection were autographically recorded by the testing machine.

Some of the resulting diagrams are reproduced in Fig. 3. The height of each curve represents the maximum load applied to

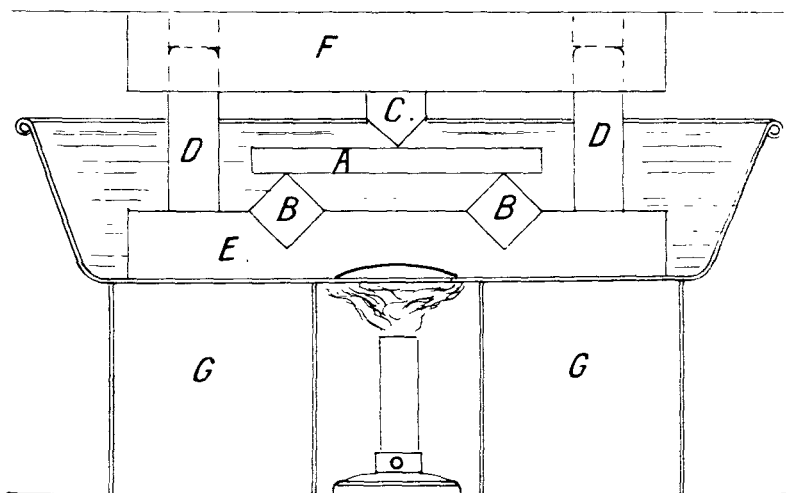


FIG. 2.—Apparatus used in Breaking Tests.

the specimen to break or bend it, and this maximum load is taken as a measure of toughness. Curve *a* is from a specimen

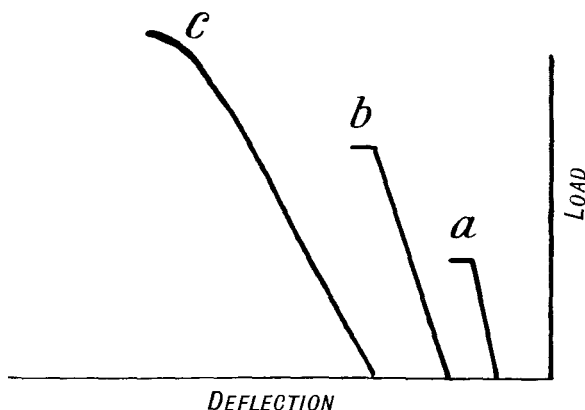


FIG. 3.—Autographic Diagram of Breaking Tests.

broken cold: being brittle, a small load sufficed to break it. Curve *b* is from a similar specimen broken at 238° C. It

was tougher, and broke at a higher load. Curve *c* is from a specimen tested at 278° C. In this case the specimen was very tough. It supported a heavy load, and bent without breaking.

For the purpose of the investigation it was necessary to ascertain the hardness of the specimens at each temperature as well as their toughness. The somewhat elusive quality of hardness may be defined as the power of resisting deformation under stress. It is commonly measured by pressing a hard steel ball into the surface of the specimen with a definite force. The material which takes the smallest impression or, in other words, which shows the greatest resistance to deformation, is taken to be the hardest. The ball test cannot be applied to very hard materials, but the diagrams in Fig. 3 give us a means of measuring resistance to deformation or hardness. The relation between the load and the resulting deflection is shown graphically by the slope of the curve. Specimen *a* was very hard: it gave only a small deflection for each increment of load, and the resulting diagram is nearly vertical. Specimen *b* was softer, and *c* very soft, and the slope of the diagram was greater as the hardness diminished. Numerically the hardness may be expressed as the load required to produce $\frac{1}{10}$ -inch deflection, and the hardness number is obtained by dividing the maximum load in pounds by the deflection in tenths of an inch. $H = \frac{L}{10D}$.

Experiments were first made on a crucible steel containing about 1.3 per cent. carbon. A bar $\frac{1}{2} \times \frac{1}{4}$ inch in section was cut into pieces 3 inches long, which were heated to 800° C. and quenched in water. Some of the specimens were left in the dead-hard state, others were tempered by being placed for fifteen minutes in an oil bath at 136° C. Others were tempered in like manner at 145° and 175° respectively. The problem was to ascertain how the physical properties of steels thus treated would be affected by the heat generated in cutting at various speeds. It was certain that a very high cutting speed would heat the cutting edge of the tool sufficiently to soften it and cause it to be blunted immediately, but it was not known what would be the effect of the lower temperatures generated at lower cutting speeds. In order to reproduce

these temperatures artificially, the specimens were heated in the apparatus illustrated in Fig. 2, and broken at various temperatures as described.

The results of the breaking tests are plotted out in diagrams A, B, C, D, Fig. 4. The full lines in these diagrams represent maximum loads at which the specimens were broken or bent (toughness), and the dotted lines represent the hardness, or maximum load divided by deflection.

Referring first to the toughness curves (full lines), it will be seen that the diagrams have certain features in common. There is a decrease of toughness as the temperature rises from that of the atmosphere to 100° , and a more or less regular increase of toughness between 100° and 250° or 275° .

Referring now to the dotted curves representing hardness, we again see certain characteristics common to all the specimens. The hardness was relatively high at atmospheric temperature, it was very much less at 50° or 100° , it again attained a high value at temperatures varying from 150° to 250° , and it fell very low at 275° to 300° , at which temperatures the specimens were so soft as to bend without breaking. It will be noticed that the hardness and toughness curves have widely different shapes, an increase of the one quality being very generally accompanied by a decrease of the other, though both decrease together between 20° and 100° .

We have here, according to our theory, two of the elements for determining the variations of durability with temperature; but it is very difficult to say, from inspection of the curves, which temperature might be expected to give the highest durability to the steel. The durability will be high when both the hardness and toughness are high. The durability will be low when either the toughness or hardness, or both, are low. Now it is evident that if we multiply the hardness number by the corresponding toughness number for each temperature, we shall obtain a new series of numbers fulfilling the conditions just stated—they will be high when the hardness and toughness are both high; they will be low when either hardness or toughness, or both, are low. These numbers should therefore be in some degree proportional to the durability of the steel. We cannot say that they will be strictly proportional to dura-

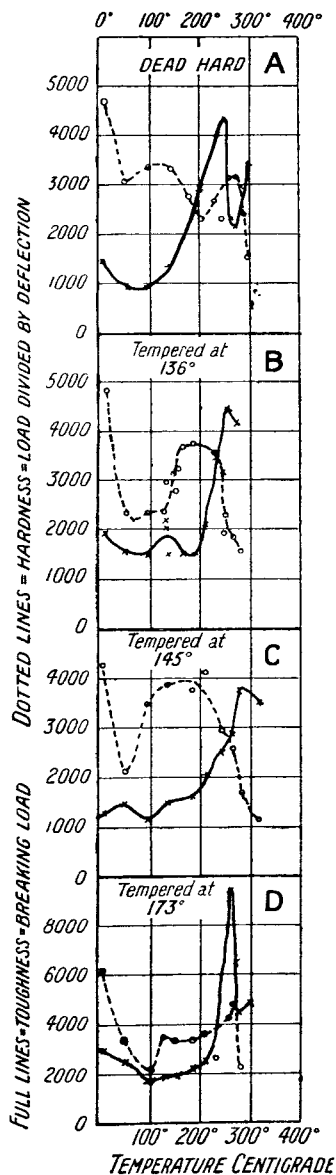


FIG. 4.—Curves representing Toughness (full lines) and Hardness (dotted lines) of Carbon Steel variously tempered.

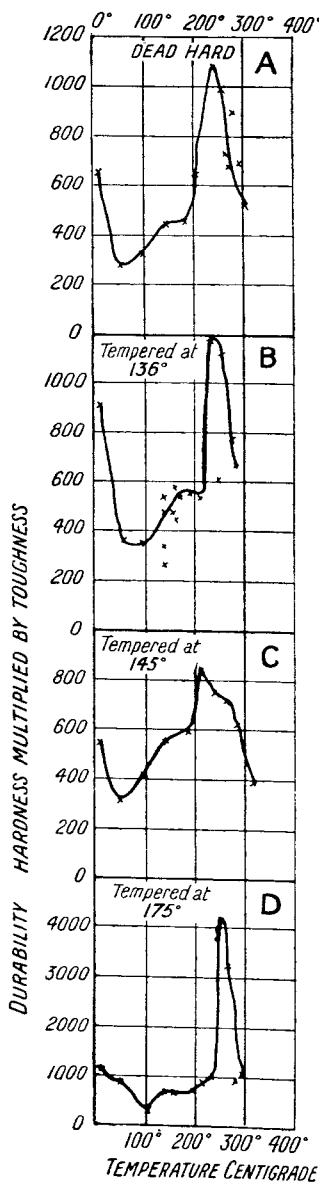


FIG. 5.—Temperature-durability. Curves from Breaking Tests, Carbon Steel.

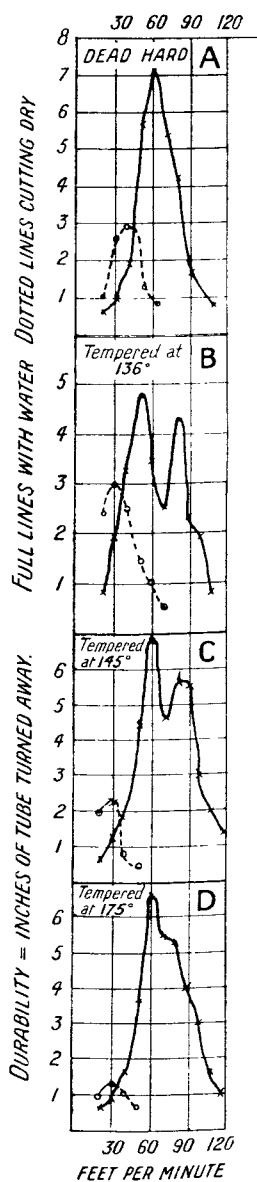


FIG. 6.—Speed-durability. Curves, from Cutting Tests, Carbon Steel.

bility unless we assume that hardness and toughness are the only qualities constituting durability, and that they are equally important factors in durability, but these are assumptions we have no right to make. Either hardness or toughness may be the more important factor, according to the nature of the material the tool is required to cut. It is an established fact that the steel which is best for cutting hard materials such as tyre steel is not necessarily the best for cutting soft materials such as mild steel or brass, and this may be because a harder tool is required for one class of material and a tougher for the other. Nor can we safely assume that hardness and toughness are the only factors in durability. Some steels (notably the tungsten steels) possess a property of resisting abrasion which does not appear to depend directly on hardness or toughness, and can only be measured by an abrasive test—preferably an actual cutting test. A breaking test may give no evidence of the presence or absence of this quality. The evidence to be obtained from the breaking tests must therefore be regarded as mainly negative evidence. It is certain that a tool which is very soft or very brittle will not be durable. It is almost certain that a given tool will gain in durability as it becomes harder and tougher; but it by no means follows that the specimen of steel which carries the heaviest load with the least deflection will make the most durable cutting tool.

Recognising, then, that the product of hardness and toughness may bear only an approximately proportional relation to durability, let us examine the curves produced by plotting these products on a temperature basis. The curves are shown in Fig. 5, and the durability-speed curves obtained from specimens of the same steel by actual cutting tests made on the tool steel testing machine are shown in Fig. 6. Two sets of curves are shown in this figure. The full lines represent the durability of tools cutting under water, and the dotted curves are taken from the same tools cutting dry.

It is at once apparent that there is a very striking similarity between the curves obtained by breaking (Fig. 5), and

those obtained by cutting (Fig. 6). In each case there is a very low durability at low speeds or temperatures, a rise to a high maximum as the speed or temperature increases, and a fall to a low value when the speed or temperature exceeds a certain value. It is especially noticeable that the range of speeds and temperatures which gives the steel a high durability is a very narrow one. One important difference will be noticed. The breaking tests all show a high durability at atmospheric temperature and a rapid fall to 50° or 100° , but this feature is entirely absent from the curves obtained by cutting. From this it might be surmised that at the lowest cutting speed, viz. 20 feet per minute, the edge of the tool was at 50° to 100° , and that the tools would have a higher durability when cutting at still lower speeds. Some experiments have been made with a view to confirming this inference, but hitherto without success. Tests were made at speeds as low as 2 feet per minute, and the tool was flooded with a freezing mixture, but the wear was extremely rapid, and no increase of durability was found. There is no doubt a considerable amount of heat generated in cutting a tough steel, no matter how slow the speed, and it may be that the cutting edge was considerably above atmospheric temperature even under the extreme conditions mentioned. This point, however, requires further investigation.

Two of the tools used in the cutting tests, namely, those tempered at 136° and 145° , gave double-peaked curves. It had previously been found (see Fig. 1) that carbon steels tempered between 130° and 150° give curves of this character, and one purpose of the investigation was to find an explanation of this phenomenon. It cannot be said that the explanation is complete, though each of the breaking tests, and especially B, shows a rudimentary first peak. The relation between the hardness and toughness curves is complicated, their maxima and minima generally failing to coincide, and it is not surprising that the resultant curve of durability should assume a complicated form. It has already been pointed out that the actual shape of the durability curve will depend on the relative importance of the hardness and toughness factors, and that this will depend on the cutting condi-

tions. It has been found by experiment that the shape of the curve is by no means constant when the cutting conditions are altered. Thus Fig. 7 shows durability-speed curves obtained from the same tool ground with 0° , 5° , and 10° rake. The height of the first peak diminishes as the rake of the tool is increased. Again, it is seen in Fig. 6 that tools which give a double peak when cutting under water usually give only a single peak when cutting dry. In this connection it may be pointed out that the cutting temperature is much more definite when the tool is cutting under a copious stream of water than when cutting dry. In the former case the extreme edge of the tool, embedded in the metal, is heated to a temperature depending on the speed and remaining constant throughout the test. When no cooling medium is employed, the tool, the tube, and the adjacent parts of the machine become gradually hotter as the test proceeds, the temperature becoming constant only (if at all) when the generation of heat is balanced by radiation. This may account for the fact that dry cutting tests seldom, if ever, give double-peaked speed curves.

Breaking tests were made with high-speed steels of two well-known brands. The specimens, $3 \times \frac{1}{2} \times \frac{1}{4}$ inch, were hardened by being preheated for $2\frac{1}{2}$ minutes at 850° , then heated for 50 seconds at 1275° , and quenched in salt bath at 672° for 30 seconds. The hardening of all the carbon and high-speed steel specimens used in these experiments was kindly undertaken by Mr. S. N. Brayshaw. The breaking tests were carried out in the manner described above, and the resulting hardness and toughness curves are shown in Fig. 8. The hardness curves (dotted) are somewhat complicated, but the curves of the two steels closely correspond with each other, and bear some resemblance to the hardness curve A (Fig. 4), taken from the dead-hard carbon steel. There is a marked fall in hardness from atmospheric temperature to 50° and 100° , followed by a rise to 130° , a fall to 280° , with a smaller rise and fall at higher temperatures. The two toughness curves (full lines) also correspond in general form, though there is a great difference in the temperatures at which the first minima occur (100° and 220° respectively).

Multiplying together the hardness and toughness numbers

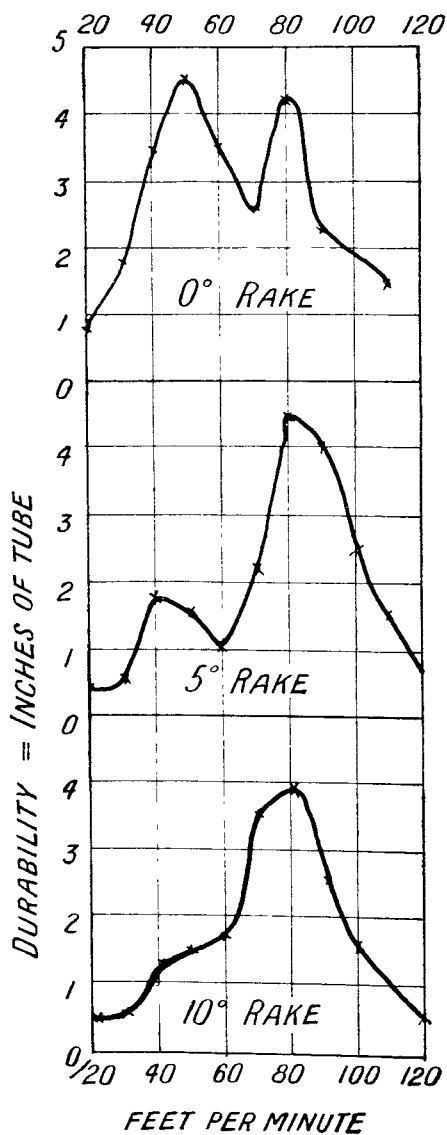


FIG. 7.—Speed-durability Curves from the same Tool, differently ground.

as before, we obtain the durability-temperature curves in

Fig. 9. The durability-speed curves obtained from two of the specimens by cutting tests on the tool steel testing machine are given in Fig. 10, the dotted curves being obtained by cutting dry, and the full curves with water.

The durability-temperature curves (Fig. 9) resemble those of the carbon steels (Fig. 5) in showing a marked fall in durability from atmospheric temperature to 50° , this feature being entirely absent in the curves obtained by cutting (Fig. 10). Both the temperature-durability curves, E and F (Fig. 9), show marked double peaks, and it will be noticed that in the case of steel E the first peak occurs between temperatures 100° and 260° , thus corresponding roughly with the main peaks of the carbon steels (Fig. 5). The second peak in steel E occurs between 260° and 400° , at which temperature the carbon steel would be soft.

Turning now to the cutting tests, we see in curve E (Fig. 10) two peaks, the first occurring between 20 and 120 feet per minute, thus corresponding with the carbon steel curves in Fig. 6, while the second peak in E (Fig. 10) occurs at 140 feet per minute, at which speed the carbon steels were incapable of cutting. There is thus a close correspondence between the durability curves obtained by breaking and by cutting tests. It is true there is a great disparity as regards the relative heights of the two peaks, but this was to be expected. Even though the steel were equally hard and tough when cutting at 70 and at 140 feet per minute (as would appear from Fig. 9), the higher speed would naturally blunt the tool more rapidly.

The curves of steel F are somewhat anomalous. The breaking tests show two distinct peaks with a low minimum at 220° , the second peak being a very large one, whereas the cutting tests (Fig. 10) show only a single peak extending from 20 to 150 feet per minute.

The dotted curves obtained by cutting dry (Figs. 6 and 10) are in all cases to the left of the corresponding "wet" curves, and it is especially to be noted that all the tools when cutting at very low speeds were more durable when water was not used—*i.e.* when they were allowed to become heated.

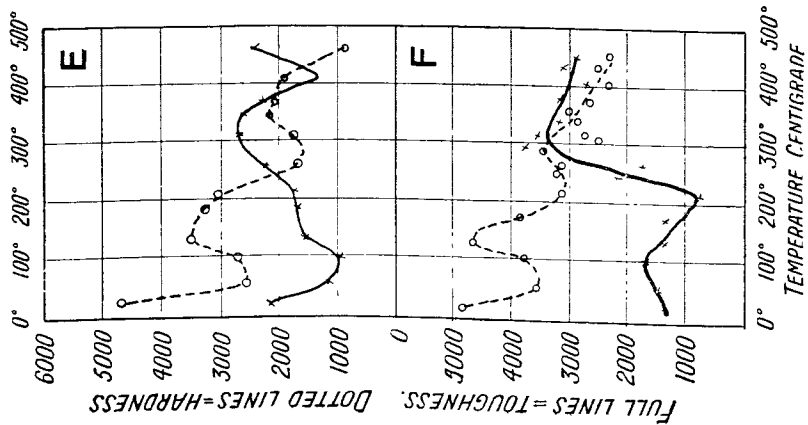


FIG. 8.—Curves representing Toughness (full lines) and Hardness (dotted lines) of two High-speed Steels, broken at various temperatures.

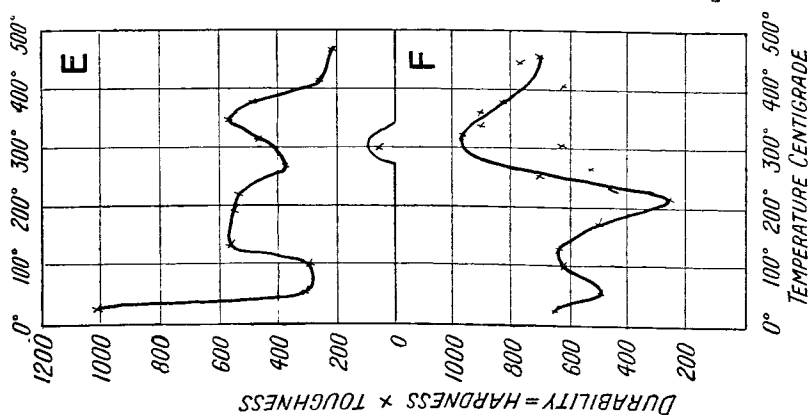


FIG. 9.—Temperature-durability Curves from Breaking Tests, High-speed Steel.

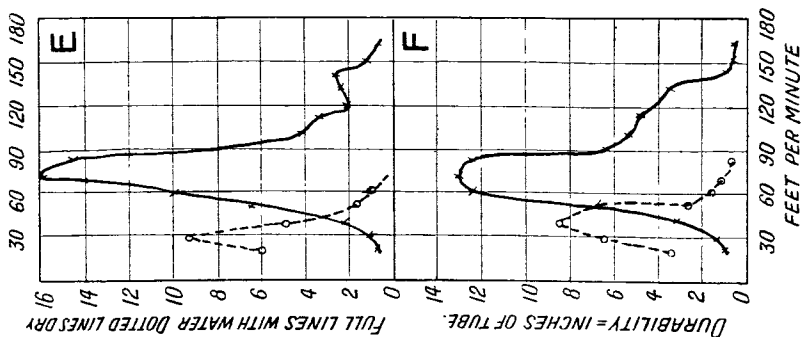


FIG. 10.—Speed-durability Curves from Cutting Tests, High-speed Steel.

This effect of temperature on durability is clearly shown in Fig. 11, which represents the speed-durability curves of a high-speed steel tool cutting (1) dry, (2) with lard oil, (3) with water. At the low speeds, 20 and 30 feet per minute, the tool was most durable when cutting dry, and least durable with water. At the highest speeds the position is reversed, while at intermediate speeds the lard oil gave the highest durability. The oil appears to exercise a double function. It acts as a cooling medium, and enables the tool to work at much higher speeds than are practicable when cutting dry; but, as a cooling medium, it is inferior to water, and therefore less conducive to durability at very high speeds. It has, however, a lubricating effect which is not possessed by water, and is highly conducive to durability at speeds which do not generate an excessive amount of heat. The oil gives the highest durability, but not at the highest speed.

The curves in Fig. 12 illustrate the extreme importance of the time factor in the hardening of high-speed steel. The dotted curve represents the durability of a high-speed tool which was preheated for 4 minutes at 850° , heated for 1 minute at 1275° , and quenched in salt at 675° C. The full curve shows the durability of the same steel preheated for $2\frac{1}{2}$ minutes and heated for 50 seconds at the same temperatures. Evidently the first tool had been injured by too prolonged heating.

Let us now see how far the results of the experiments enable us to answer the questions with which we set out.

A. The low durability of all tool steels, cutting under water at low speeds and light cuts, seems to be completely explained by the low values of hardness and toughness which always occur at cutting temperatures of 50° to 100° . The breaking tests have shown in every case that the product, hardness \times toughness, increases in value as the temperature is raised above 100° . The cutting tests have shown in every case that the durability increases when the cutting speed is raised above 20 feet per minute. These cutting tests have also shown that the durability always increases when a tool working at 20 feet per minute is allowed to cut dry instead of with water, or with hot water instead of cold. It is im-

possible to doubt that these are different manifestations of the same physical change in the steel.

A clear recognition of this phenomenon is of great practical importance. A great deal of the metal cutting in every engineer's shop consists in taking fine finishing cuts, often with water on the tool. If such cuts are taken at a slow speed, the temperature of the cutting edge may not rise above 100° , in which case the tool will be quickly blunted. Its

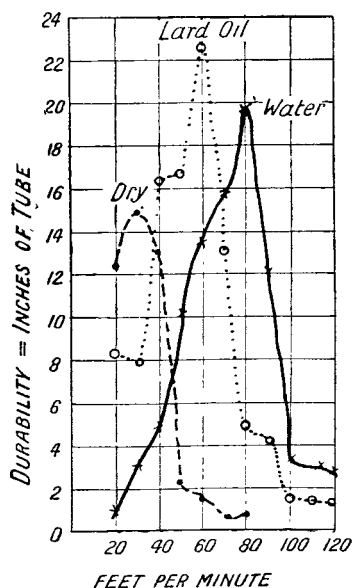


FIG. 11.—Speed-durability Curves of a High-speed Steel cutting with and without Lubricants.

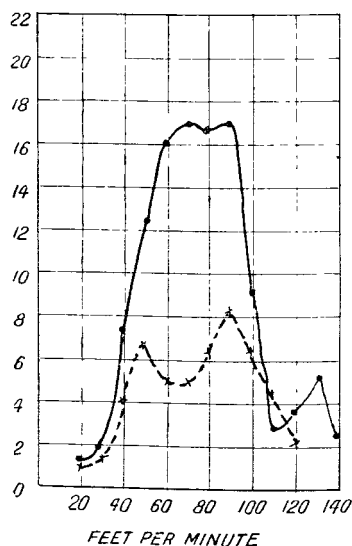


FIG. 12.—Speed-durability Curves of the same High-speed Steel differently hardened.

durability can be increased by increasing the speed or by cutting dry. Many cases are known to have occurred in ordinary workshop practice, where an increase in cutting speed has actually resulted in increased durability of the tool.

Low durability at low-cutting temperatures (on, for example, finishing cuts) is a familiar characteristic of high-speed steels, and is most marked in tools which have been suitably hardened

for very high temperature work.¹ High-speed steel can be so hardened as to retain its durability at fairly low temperatures and there are now on the market tungsten steels specially adapted for low-temperature work, such as finishing very heavy forgings; but every description of steel known to the writer loses its durability if the cutting temperature is low enough. It should be noted that a low cutting temperature can only occur when there is a combination of low speed with light cut. A heavy or moderate cut raises the temperature of the cutting edge above 100°, even at very slow speeds.

B. The phenomenon of the double-peaked curve is not completely elucidated, though the evidence goes some way to explain it. The variations of hardness and toughness with temperature are of a complicated character, and the cleft between the two peaks of a durability curve appears to be caused by the conjunction of depressions in the hardness and toughness curves at a particular temperature. The relative heights of the two peaks are found to vary with the conditions of cutting, and this variation may be due to a change in the relative importance of the hardness and toughness factors, according to the quality of the material cut, or the shape of the tool.

C. The decline in durability which takes place when a certain limiting speed is exceeded, is evidently caused by an actual softening of the cutting edge by the heat generated in cutting. This softening, which is extremely local, takes place even when the tool and the work are practically immersed in running water. The speeds and temperatures at which the softening occurs depend largely on the particular hardening process which has been applied to the tool, and are generally highest in high-speed steel.

D. It is not yet possible to establish an exact scale of cutting temperatures corresponding to the scale of cutting speeds, but a comparison of the temperature-durability curves obtained by breaking tests (Figs. 5 and 9), with the speed-durability curves obtained by cutting tests (Figs. 6 and 10), enables us to make an approximation, as in Fig. 13.

¹ There is reason to believe that the condition of low durability in such steels may occur at temperatures much higher than 100° (see F, Fig. 9).

To establish a correspondence between the speeds of cutting with and without water, a comparison may be made between the full and dotted curves in Figs. 6 and 10, from which it appears that the effect of using water is approximately to double the cutting speed; in other words, the edge of a tool flooded with water attains about the same temperature as the edge of a tool cutting dry at half the speed. This must not be taken as a general statement applicable to all cutting operations. The dry cutting temperature depends largely on the volume of metal operated upon. The tube used in the tool steel testing machine is small in diameter and light in section; it becomes considerably heated under a dry cut. In machining a large forging, the body of metal absorbs a

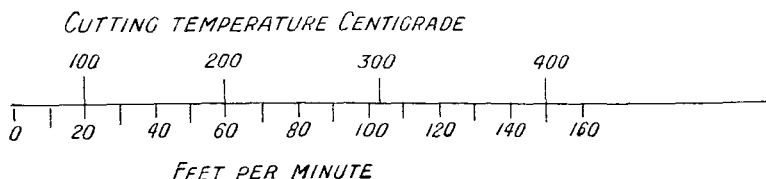


FIG. 13.—Approximate Scale of Cutting Temperatures and Speeds for Tools cutting with Water on the Tool Steel Testing Machine.

great deal of heat, with only a slight rise in temperature, and the use of water has less effect on the cutting speed.

Considerable interest attaches to a comparison of the durabilities of carbon and high-speed steels. It appears from Figs. 6 and 10 that the high-speed steel has two distinct features of superiority. The speeds at which it attains its maximum durability are not very different from those at which carbon steel is most durable, but the high-speed steel is several times as durable at these speeds. Quite distinct from its superior durability at moderate cutting temperatures is the property possessed by high-speed steel of retaining some durability at temperatures high enough to soften carbon steel, but its actual durability under such conditions is much less than under conditions which do not unduly heat it. In other words, its abrasive quality appears to be more important than its heat-resisting quality.

A comparison of the curves in Figs. 5, 6, 9, and 10 lends force to the warning already given, that no absolute measure of durability can be obtained by a breaking test. The highest durability calculated from breaking tests was that of tool D, but the actual durability of this carbon steel, measured by cutting, was not particularly high, and was much less than that of high-speed steel E, which broke under lower loads.

DISCUSSION.

Mr. L. ARCHBUTT (Derby) said he would like to ask Mr. Herbert if he had made any experiments with Aquadag deflocculated graphite, which was invented by Dr. Acherson. He understood that when used with water it immensely increased the cutting power of tools.

Mr. HERBERT, in reply, said he had had no experience of the lubricant described by Mr. Archbutt. His experiments had shown that water was under some conditions superior to oil, for use with cutting tools, on account of its greater cooling power, but that in lubricating the tool and reducing friction it was inadequate. He could imagine that the addition of graphite to the water might render it more efficient as a lubricant without impairing its properties as a cooling medium, in which case, the curve he had exhibited would retain its position, but would show a higher durability. He could not, however, say definitely that that would be so without having made experiments.

CORRESPONDENCE.

Mr. S. N. BRAYSHAW (Manchester) wrote saying he could confirm from his own experience the "peak" which Mr. Herbert had discovered in speed-durability curves, and in some cases he had suspected a double "peak." Most turners would probably say, if the question were definitely put to them, that the wear of the tool was proportionate to the cutting speed, but he suspected that in actual practice they knew that they would get bad results if they ran too slow. He remembered an occasion when he was an apprentice and was told to run on a faster speed because the tool was working badly. The following might serve as an actual example of what occurred in his own works. A large quantity of tool steel bars $\frac{3}{4}$ -inch diameter were being turned up, and for some time the machines ran at 195 revolutions per minute, which gave a cutting speed of 38 feet per minute on the largest diameter. The tools dulled very quickly, and had to be resharpened on an average once every forty-five minutes. The speed was then increased to 330 revolutions per minute, giving a cutting speed of 65 feet per minute, other conditions remaining the same. The consequence was that the life of the tools was increased to about three hours, which meant an increase of nearly sevenfold in the actual work done by the tool for every sharpening.

That was not an isolated case, and it was a striking confirmation of Mr. Herbert's results; or to put it another way, Mr. Herbert had investigated the matter, and had explained some very curious facts of which very little knowledge existed, and his researches would undoubtedly be of great assistance in workshop practice.

NOTE ON THE INVESTIGATION OF
FRACTURES.

BY F. ROGERS, D.ENG. (SHEFFIELD).

It is rarely possible to investigate systematically the cause of an unexpected fracture by known methods without rather long and laborious research. The consequence is, that more or less pardonably, this is made the excuse, in the majority of cases of tests to destruction, for not investigating at all. Since a large class of failures, including principally all faults which may broadly be classed as some form of segregation, and usually excluding heat treatment, is due to more or less localised fault, it is highly desirable that the fracture itself should be studied if possible. The general appearance and so-called "grain" of the fracture, and possibly any non-metallic inclusion, if not too minute, can easily be noted, but it is notorious that every attempt to obtain information about structure by applying the microscope directly to the fractured surface has failed.

A few methods have been suggested for obtaining a cross-section through the fracture, and examining this by means of the microscope. In Rosenhain's method,¹ copper is heavily deposited upon the fracture during about eight days. I have obtained good results without this delay by gently pressing a number of leaves of Dutch metal (imitation gold leaf) into contact with the fracture, and binding by means of a small steel clamp. Doubtless quite perfect results could be obtained by a combination of the two methods—that is, after depositing copper for a short time, perhaps three or four hours, in order to form a more perfect mechanical protection for the fracture, leaves of Dutch metal could be clamped against the copper.

Another useful method is to cast a fusible alloy, melting at about 100° C., against the fracture. This also generally requires the use of the clamp.

¹ *Journal of the Iron and Steel Institute*, 1906, No. 11, p. 189.

The drawback to such methods is that they are very laborious, giving little more than a mathematical line upon the actual fracture for each section taken, and there is always the possibility that the ultimate cause of weakness may not lie in one of the sections taken. Consequently, it occurred to me that, if even a comparatively rough chemical examination of the fractured surface could be made, as for example by a method of contact printing, it might be quite as valuable on the whole as the more elaborate microscopic methods; and whilst giving sufficient indication for many practical purposes as to the cause of failure, it might also in other cases be useful as a preliminary to the examination by the elaborate methods, thus indefinitely minimising labour spent upon trying to find the position of the fault which had caused the trouble.

After experiments in several directions, I have adopted a method which is virtually a modification of the well-known method of obtaining a "sulphur print" from a cut surface. A piece of a specially prepared tissue, which consists of a gelatine emulsion of silver bromide, coated upon a very stiff grease clay, is soaked in a dilute acid solution containing also a toughening agent, and immediately pressed into contact with the clean fracture for a few seconds and withdrawn. The entire process occupies no more than a minute. Precise details are given in the Appendix.

In order to find whether it would be possible to interpret with certainty the meaning of such a print, it was desirable to determine what relation exists between a print from a fracture, and a print obtained by the ordinary method from a neighbouring cut section, and also to establish what nature of contrast was to be expected between an actually segregated region and an unsegregated region in the same fracture. On this account some prints are shown (see Figs. 1 to 8, Plate XXXVII.) for mutual comparison, which have been made upon cut sections and fractures by the special tissue, and upon cut sections and fractures by means of a standard make of bromide paper, which is frequently used in sulphur printing. Bromide paper was in fact one of the first means tried for printing from a fracture, and it was found necessary to press or hammer it

into contact with the aid of the same stiff clay subsequently used for making the tissue. The effect of different durations of contact of the print with the metal is also shown. The reproductions are accompanied by an explanatory legend.

The first and most striking fact that was established was that the printing of a fracture proceeds at an astonishingly greater speed than the printing of a neighbouring cut surface. This is shown by a comparison of Fig. 4 (fracture) with Fig. 3 (cut). In these the depth of printing has been restricted by using very dilute acid and brief duration of contact. A print from a fracture made with the same concentration of acid and duration of contact as either Nos. 1, 2, or 5, which approximate to the ordinary method of sulphur printing from cut surfaces, would show only an unrecognisable black smudge. If one may, for argument's sake, assume—what is not necessarily strictly accurate—that the proportion of sulphur indicated is inversely proportional to the duration of contact and concentration of acid necessary to give a print of a definite depth of colour, then it appears that the percentage of sulphur indicated by a print from a fracture is of the order of one hundred times as great as that indicated by a print from a neighbouring cut section. This cannot mean anything else, I think, than that the fracture has picked its way through the minute sulphide specks with correspondingly great preference. This would not be surprising if we were dealing with an alloy containing say 0.4 per cent. of sulphur, in which the manganese sulphide would be expected to form a network. In steels containing less than 0.04 per cent. of sulphur, we are well aware that the sulphide rarely exists as a partial network, but almost solely as minute isolated, cigar or lens-shaped particles, lying in the direction of the length of the forging or of rolling.

It is interesting in this connection to recall that at a meeting of the Sheffield Society of Metallurgists and Engineers in January last, Dr. Stead showed a photomicrograph of a sulphide area in a piece of steel which, after polishing, had been bent in a plane at right angles to the surface photographed. An incipient crack was seen to have travelled through the little area of manganese sulphide, and to be

making its way into the metal at each of its ends. I hope that it will be convenient for Dr. Stead to contribute this photograph to the discussion.¹

It may conceivably be argued that the relatively rough preparation of the cut samples for printing has, by causing a certain amount of "flow" of the surface of the metal to cover and so protect the sulphide, been in part responsible for the great difference between cut surfaces and fractures respectively. This is not so, however, for a piece of steel gives much the same depth of colour, whether printed as roughly cut off, or after smooth filing, or after polishing on emery papers, or after polishing as for careful microscopic examination. Further, much protection is hardly to be expected, as the acid would probably soon dissolve away any possible thin film of metal; and in any event, unless a sulphide speck were thoroughly covered, it would not be effectually protected from the action of the acid. The great difference between a print from a fracture and a print from a neighbouring cut surface seems to be independent of the mode of fracture; it is found to be of the same kind, whether the fracture was caused by tensile stress, slow bending, repeated severe bending, or shock. It is also of the same sort in steels ranging from dead mild up to 1.3 per cent. carbon tool steel.

It seems to me that the extraordinary degree of selection of a path through the specks of manganese sulphide as the line of least resistance to fracture strongly confirms the desirability of keeping sulphur low, if any confirmation be needed. No known method of treatment will bring the sulphur into a less harmful form than the usual little longitudinally arranged rods or lenses of manganese sulphide. Hence the inherent unsoundness of the remark one sometimes hears, to the effect that '0.05 per cent. of sulphur would be equally safe' in steels which now usually contain under say 0.035 per cent., apart from the absence of any margin of safety for local variations from the analysis taken in the usual position.

It is quite probable that the path of least resistance also

¹ [A photomicrograph which illustrates this point is given in Dr. Stead's paper (*ante*, Fig. 11, p. 113).—ED.]

follows, in a similar manner, the minute high phosphorus regions, so far as is compatible with the difference in the forms in which phosphorus and sulphur are known to occur in steel. Perhaps a printing method could be devised to establish this, but it was considered that a sulphur method would be quite sufficient for most practical applications, and on the whole preferable to a phosphorus method as an index of segregation.

The present expression of opinion, that the selection of the path of fracture is largely biassed to the actual sulphur and phosphorus bearing areas, is by no means inconsistent with the view¹ that fracture in low to medium carbon steels, under repeated alternations of stress, tends to prefer a path through ferrite, which has been confirmed by others for different kinds of stress. Not only has pure, well crystallised ferrite a peculiar weakness of its own under dynamic stress, but in steels which contain ferrite, the tendency for the sulphur and phosphorus to be associated geographically with the ferrite is well understood.

There seems to be no doubt that the method of printing from a fracture here described, although, as may be expected, rather a rough-and-ready than a pretty test, can, with a little care and practice in its use, be relied upon to indicate a segregated area in a fracture. There are slight variations in the depth of colour in the print, due to the differences in contact pressure over the various irregularities of the surface. One soon learns how to allow for these by observing the shape of the surface, which is also shown in its impression in the tissue.

Some examples of prints from fractures are given in Figs. 9 to 12, Plates XXXVII. to XXXIX., and the position of the segregation, if any, is indicated. It should be borne in mind that part of the variation of depth of colour in the reproductions at places where no segregation is indicated, is due to the light and shade effect, caused by the fact that the print is also an impression of the fracture.

Fig. 9, Plate XXXVIII., shows a print on the special tissue taken from a part of the fracture of a high-class steel tire. The

¹ *Journal of the Iron and Steel Institute*, 1905, No. 1. p. 491.

position of the bore is shown, and it is seen that a satisfactory print has been obtained along the full length of the bore, and extending about an inch and a half inwards from the bore. This is more than is ordinarily likely to be necessary for this class of tire. This fracture, which was deliberately made for the purpose of printing, shows no signs of segregation.

Fig. 10, Plate XXXVII., is a print made upon ordinary bromide paper, which was toughened by soaking in formalin before use, taken from the fracture of a portion of the core of a tire bloom of the same class as the tire from which Fig. 9, Plate XXXVIII., was obtained. In this print the lines of segregation are clearly visible, and the fact that these lines really do represent segregation, is amply confirmed by the print given in Fig. 11, Plate XXXVII., which was made in quite the ordinary manner of sulphur printing, from a parallel section, only a small fraction of an inch away from the fracture printed in Fig. 10.

Fig. 12, Plate XXXIX., represents a print upon the special tissue taken from a rail in a position as near as was convenient to the topmost portion of the ingot used. In spite of this, no marked segregation is shown. The print is merely a trifle darker generally, towards the web of the rail. In this case, the head, web, and base were printed on three separate portions of tissue, and subsequently pieced together. The lighter areas in the base were caused by allowing some splashes of the acid solution to fall on this portion whilst printing from the web.

In conclusion, it is hoped that the rough-and-ready method of printing from a fracture here brought forward, will be found useful whenever unexpected results are obtained in tests to destruction, such as in falling weight tests of rails, tires, or axles, in tensile tests of all kinds of material, and bending tests of plates. It is probably the simplest and quickest method of investigating a fracture at present available, and should show instantly whether breakage has been assisted by segregation or not.

With obviously necessary precautions, there is no reason why the method might not be applied to a fracture which has occurred in service.



FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.



FIG. 5.



FIG. 6.



FIG. 7.



FIG. 8.

Prints from Cut Sections and Fractures.

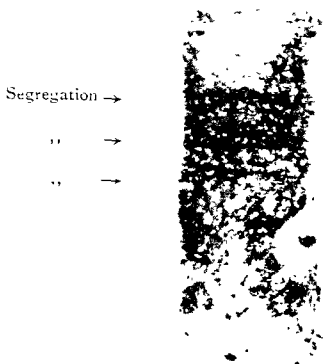


FIG. 10.—Print on bromide paper from a Fracture of part of the Core of a Tire Bloom.

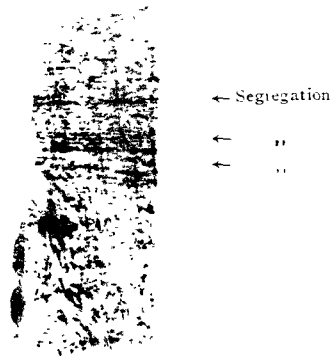


FIG. 11.—Same as Fig. 10, but a neighbouring cut section.



FIG. 9.—Print from part of Fracture of a Steel Tie. The position of the bore is indicated.

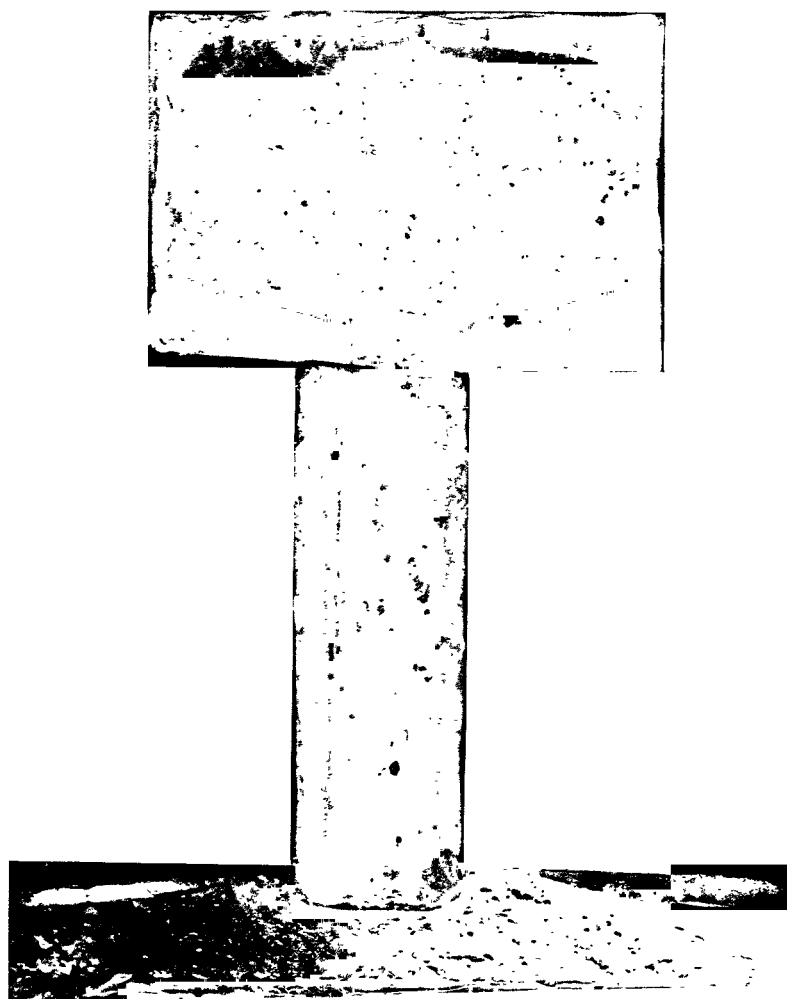


FIG. 12.—Print from Fracture of a Steel Rail.

APPENDIX.

· DETAILS OF PREPARATION AND USE OF THE TISSUE.

It is hoped that it will soon be possible to purchase the tissue prepared ready for use. In the meantime, the following details will enable any one to prepare a supply which can be stocked for use as required—

Clay.—Melt together 1 lb. of vaseline and one ordinary wax candle. The minimum possible quantity of the mixture that will give a stiff cohering clay is incorporated with finely ground and dried whiting. This is rolled into sheets about $\frac{1}{16}$ inch thick. Plasticene is too soft for the purpose, and its colour is against it, but it will answer if stiffened by the addition of whiting.

Silver Bromide Emulsion.—Digest the following together at about 43° C.—

Water	150 cubic centimetres.
Gelatine	15 grammes.
10 per cent. hydrochloric acid	3 cubic centimetres.
Potassium bromide	8·4 grammes.

Then add the following solution, also heated to 43° C.—

Water	50 cubic centimetres.
Silver nitrate	10 grammes.

The whole is digested at about 43° C. for about a quarter of an hour. Chill rapidly to set, cut up, wash in a jelly-bag for two hours, remelt, add a further 15 grammes of gelatine, and the emulsion is ready to be coated upon its support. It can be stored by allowing it to set, and putting a little carbolic acid in alcohol upon the surface.

Coating.—Warm a sheet of the clay, sprinkle finely powdered calcium sulphate upon it, rub lightly until greasiness is removed, dust off the excess of calcium sulphate. Immediately pour a little of the melted emulsion on, and spread with a glass rod, and by tilting the sheet about. Leave in a horizontal position to dry.

To take a Print from a Fracture.—Soak the tissue for twenty to thirty seconds in—

Water	100 cubic centimetres.
Sulphuric acid	1 cubic centimetre.
Alum	5 grammes.

See that the surface of the gelatine is well wetted by the solution, which is assisted by gently stroking with the finger, then instantly apply and press into contact by means of the fingers. Withdraw the print in about twelve seconds, or rather longer in the case of exceptionally pure steels. Chiefly on account of the difficulty of keeping the whole of the tissue satisfactorily wetted, it is on the whole best, in the case of large and very irregular fractures, to print the surface in several overlapping portions. It is quite easy to print a very irregular fracture in pieces about 3 by 2 inches, whilst with a fairly regular surface, 5 by 3 inches gives no trouble.

Fixing.—This can be done as usual for a print, in hypo., but, owing to the risk of stripping the gelatine from the clay, is best omitted. It is sufficient to rinse the print gently, and allow to dry at once.

Much depends on keeping both the solution and the steel cool; the temperatures should not exceed about 20° C. A little practice is necessary in order to know how much pressure to use. It is worth remembering that there are usually two fractured surfaces to each fracture.

Description of Figs. 1 to 8 (Plate I.).

Figure.	Printed upon	Sulphuric Acid per Cent	Duration of Con- tact, Minutes.	Surface.
1	Bromide paper	1	5	Cut.
2	Do.	5	1	Cut.
3	Do.	1	$\frac{1}{2}$	Cut.
4	Do.	1	$\frac{1}{2}$	Fractured.
5	Ti-sue.	1	5	Cut.
6	Do.	1	$\frac{1}{2}$	Cut.
7	Do.	1	$\frac{1}{2}$	Fractured.
8	Do.	1	$\frac{1}{2}$	Half fractured, half cut.

DISCUSSION.

Dr. W. ROSENHAIN (Teddington) congratulated Dr. Rogers on the ingenious method which he had devised for taking sulphur prints from fractures. He was much interested in the study of fractures, and appreciated any new method introduced; but the present method had the limitation, common to all sulphur prints, that no magnification could be obtained. Thus, although the process gave a general idea of the distribution of the sulphur, a detailed knowledge could not be obtained; yet in many cases an exact detailed impression was of very great importance. On examining Dr. Rogers' prints it was difficult to say whether they represented a very large number of minute sulphide globules which might be more or less harmless or a smaller number of large ones which would be very injurious. Another difficulty with regard to Dr. Rogers' prints was that they were not flat, and when they came to be reproduced for purposes of permanent record that became a serious matter, because in the photographs it was impossible to say what was light and shade effect due to the "relief" of the prints and what was darkening due to sulphur. Probably Dr. Rogers would render his process still more useful if he could devise some means of projecting the prints on flat surfaces. Could not that be done by covering the front of the print with a layer of thick transparent celluloid and afterwards removing the opaque clay backing and looking through the print by light transmitted through the celluloid?

Then Dr. Rogers confined himself to prints of the sulphides of iron and manganese. It might, however, be possible to adopt the method of Heyn, who originated those contact prints. Heyn used mercuric chloride as a sensitive substance, and thus obtained prints of the phosphide distribution. He (Dr. Rosenhain) was particularly interested in Dr. Rogers' view as to the large proportion of sulphides to be found on fractured surfaces; any additional evidence as to the part played by sulphide enclosures would be most valuable.

CORRESPONDENCE.

Mr. C. H. RIDSDALE (Linthorpe) wrote that so far as a sulphur print of a fracture could be of any use, Dr. Rogers appeared to have devised a very good way to obtain one. He (Mr. Ridsdale) had from time to time tried to get one by pressing damp bromide paper with thick filter paper backing (much as a stereotype was taken) on the fracture, but Dr. Rogers' method appeared to be decidedly better. It was questionable, however, whether a print of the cross-section of a fracture was a guide to the cause of it; such an instance was very rare in his (Mr. Ridsdale's) experience. As a rule, unless very old or badly

damaged, it could be seen from the fracture itself at what point it had started, and a local flaw, mark of a blow, or other indication could be carefully looked for there. Almost invariably, however, if found, it was on the side view, not the front. Most readers of the paper would, he thought, carry away the impression that a considerable proportion of fractures were due to segregation, particularly of sulphur; and further, that even 0.05 per cent. was a dangerous amount. Dr. Rogers might not have intended that, but he (Mr. Ridsdale) considered that such an impression would be very misleading, especially to laymen or those who had not much experience, and, therefore, it ought to be corrected. Both sulphur and segregation as causes of brittleness were very much overrated "bogies," and although he held no brief for either, there was such abundant evidence of the fact that they could not afford to ignore it. In fact, such opinions had their stronghold in academic rather than practical circles.

He wished, therefore, to warn investigators to keep a perfectly open mind, and not to start with the preconceived feeling that if they could find from a sulphur print a little segregation that would be the cause of fracture. That note of caution, however, did not in any way detract from the credit due to the author for his very ingenious way of surmounting the difficulties of getting a print from a fracture when it was necessary.

Dr. J. E. STEAD, F.R.S., Vice-President, wrote that he had read Mr. Rogers' paper with great interest. There could be no doubt whatever that some such method as that proposed by the author would be useful when it was not practicable to get polished sections to work on. He himself had used silver bromide paper made into a pulp, which after being moistened with sulphuric acid was pressed upon fractured surfaces, and in that way he had obtained useful impressions, but not nearly so good as those obtained from smooth surfaces and acidulated bromide paper. As the author had provided him with some of his specially prepared silverised medium he had tried it in his laboratory; it gave the results which the author claimed. By its use it was very easy to find whether there was axial or local segregation of sulphur on the fractured surfaces of rails, billets, and bars.

Referring to the effect of threads or seams of sulphide of manganese in tubes, there could be no doubt that they were a disadvantage, and tended to reduce the bursting strength of the tubes. For that reason all tubes which had to bear great internal pressure should be as low as possible in sulphide of manganese. Long, continuous, and thick threads or seams of manganese sulphide on the outside portion of tubes were exactly equivalent to threads of slag or even to rakes, and if present when the steel was under tension, the seams would be liable to open out at the points where they existed, and lead to complete fracture. The photograph referred to by Mr. Rogers in a lecture he (Dr. Stead) had given in Sheffield had been reproduced on the last page of the paper on "The Welding-up of Blowholes and Cavities in Steel Ingots," and showed, just as Mr. Rogers had pointed out, that fracture starting at

a sulphide flaw might extend beyond it; but in that particular specimen the sulphide of manganese thread was embedded in material rich in phosphorus, a circumstance which was favourable for the extension of the fracture. In his opinion, sulphur segregation in the centre of rails, plates, and axles, if not coincident with unwelded "pipes," or unsoundness, should not be regarded as harmful. The appearance of fractures might indicate whether such unsoundness exists. Axial segregation was often associated with unsoundness, and he believed that failures in segregated rails were the result of unsoundness rather than of segregation.

Dr. ROGERS wrote in reply to Dr. Rosenhain's remarks, that he did not think that in practice any high sulphur areas which were not apparent without enlargement upon the properly made print would be very material. The more elaborate methods were always available, and in fact necessary, if a fault had to be further studied. He was, however, making experiments in some favourable cases in stripping the film from its support so that it could be transferred to a paper support or a lantern slide. As a transparency they must remember that the contrast would be distinctly poorer than as a print viewed by reflected light. From Mr. Ridsdale's and Dr. Stead's remarks it was evident that other investigators had felt the need of a convenient means of testing a fractured surface for sulphur, and he (Dr. Rogers) knew that others had realised the same necessity. He could by no means endorse Mr. Ridsdale's view that sulphur and segregation as causes of brittleness were overrated, as he had known disasters to occur through culpable ignoring of the importance of these imperfections. Certain kinds of products were from their form or from its relation to the ingot particularly susceptible to trouble from that cause, as for example the tubes mentioned by Dr. Stead, and tires. Relatively small external segregations, which existed more frequently than was recognised, were a source of danger in almost any article. He (Dr. Rogers) had known centrally segregated rails, which showed no evidence of unsoundness such as unwelded pipes, to fail both in test and in service. One of the most certain means contributing to the avoidance of segregation was to minimise the elements which segregated harmfully. He ventured still to hold that 0.05 per cent. of sulphur would be a dangerous specification for some important purposes. That was the opinion of the British Standards Committee which, he thought, Mr. Ridsdale would not consider an academical body. He was able to say that the method of printing from a fracture was being found useful in the ways he had suggested.

ON THE ORIGIN OF THE IRON ORES OF SWEDISH LAPLAND.

By L. LEIGH FERMOR, A.R.S.M., D.Sc., F.G.S. (CALCUTTA).

CORRESPONDENCE.

Dr. L. L. FERMOR¹ wrote regretting that he had not been able to reply earlier to Mr. Herdsman's remarks on his paper on the Laponian iron-ore deposits. They were received in camp in India away from any library, and, owing to Mr. Herdsman's references to definite pages, it had been necessary to obtain by post from Calcutta Mr. Herdsman's, Dr. Stutzer's, and his (Dr. Fermor's) own papers.

It was pleasant to discuss so interesting a subject with such a courteous controversialist as Mr. Herdsman, and he (Dr. Fermor) would say at once that he thought Mr. Herdsman had supported very ably what he (Dr. Fermor) regarded as an untenable position, namely, the sedimentary origin of the iron-ore deposits of Swedish Lapland in general, and of Kirunavaara in particular.

The two papers read side by side might serve the useful purpose of setting forth briefly the opposite sides of the question. In taking up the magmatic position he was, of course, but agreeing with many other geologists, and consequently it was unnecessary for him to treat in detail a subject that had already been dealt with very fully, especially by Stutzer and Geijer. The object of his paper was, therefore, to place before the members of the Institute a brief exposition of the magmatic view, and so to prevent, if possible, the promulgation of what he regarded as retrograde ideas on this subject.

In considering Mr. Herdsman's remarks it was well to take his last paragraph first, for in it he expressed a very comprehensive view of the origin of iron-ore deposits in general, with the following words :

"He also ventured to affirm that all known magnetite deposits without exception were thermally metamorphosed ore concentrations pre-existing as sedimentary or replacement deposits, the Norwegian and other ilmenite and titaniferous magnetite ore bodies being metamorphosed ancient fluvial or marine concentrations of those minerals such as he had previously referred to. There was thus in his opinion no room for a magmatic theory in connection with iron-ore deposits, and though that theory was much in evidence at the present time, he was confident that it would in due time be found untenable."

¹ [This communication was received too late for inclusion in the last volume of the Journal, in which Mr. Fermor's paper is published.—Ed.]

With that statement Mr. Herdsman ascribed, therefore, a non-magmatic origin to such a deposit as that of Taberg in Småland in Southern Sweden, which was regarded as one of the best and most undoubted examples of magmatic differentiation known to science. To deny the magmatic origin of that deposit was to deny not only the magmatic origin of any and every iron-ore deposit, but also (because such denial postulated the falsity of many of the fundamental conceptions of petrology, such as that gabbro was a plutonic igneous rock, and therefore of magmatic origin), the magmatic origin of chromite bodies in peridotite and serpentine, and of the nickeliferous pyrrhotites of Canada and Norway. It was desirable, therefore, to mention briefly the evidence on which a magmatic origin had been ascribed to the Taberg deposit.

At Taberg a small lens of olivine-norite (gabbro), about 2 kilometres long and 600 millimetres broad, was surrounded by gneisses, into which it was intrusive. That norite consisted of plagioclase feldspar, rhombic pyroxene, diopside, olivine, apatite, magnetite and ilmenite. As the centre of the lens was approached the rock changed gradually in mineralogical constitution into one composed of predominant titanomagnetite with olivine, with subordinate biotite and plagioclase, and known as magnetite-olivinite. That rock constituted the ore, and in its most central portion the plagioclase was completely absent. The ore mass was about 1 kilometre long and 400 millimetres broad, and formed a hill 130 millimetres high with reference to the surrounding country of norite and gneiss. It contained 31 to 33 per cent. iron with about 6 per cent. of TiO_2 . Gabbros and norites were admitted by all petrologists to be plutonic igneous rocks, and as there seemed to be no doubt about the gradual mineralogical passage of norite into magnetite-olivinite at Taberg—the ore-rock being composed of minerals found also in the norite—it could not be doubted that the central magnetite-olivinite (titaniferous iron ore) had been formed by magmatic differentiation *in situ* from the original norite magma.

Equally definite as regards origin and relationships were the rocks of the Ekersund-Soggendal region of Norway, where streaks (schlieren) of ilmenite-rock and of ilmenite-norite were found within an enormous mass of anorthosite under conditions that proved them to be genetically related to the anorthosite, which all petrologists accepted as a plutonic igneous rock of the gabbro family. Here also, consequently, there seemed to be no room for doubt as to the magmatic origin of the ilmenite bodies, which had so far yielded about 100,000 tons of ore with 36 to 40 per cent. TiO_2 and 36 to 38 per cent. Fe.

Reference to any of the general works on ore deposits would give numerous other examples of iron-ore deposits that it was practically impossible to explain concordantly with the facts as either metamorphosed sedimentary or metamorphosed replacement deposits. Perhaps the best and most convincing reading for the confirmed sedimentationist who wished to be converted would be pages 239–274 of the section entitled *Magmatische Erzausscheidungen* in that magnificent

exposition of the whole subject of ore deposits now appearing under the title of *Die Lagerstätten der Nutzbaren Mineralien und Gesteine*, by Professors Beyschlag, Krusch and Vogt. In that section might be detected the master hand of Professor Vogt, an enthusiastic magmatist. He (Dr. Fermor) doubted if Mr. Herdsman, after a careful perusal of the portion recommended, would be able to retain his sedimentary theories. Should he succeed, however, he thought he would be doing a service by explaining in print in what way the facts presented in the work referred to had been misinterpreted so as to lead many geologists to a magmatic theory when a sedimentary theory was the correct one.

Where the divergence of opinion on the origin of the iron-ore deposits of Lapland in particular, and of all iron-ore deposits in general,¹ was so absolute, there seemed to be little point in subjecting to detailed analysis Mr. Herdsman's criticisms of his paper. Nevertheless, it might be as well to treat them briefly.

In again referring to De Launay's opinion that the iron ores of Lapland were sediments, it seemed to Dr. Fermor that Mr. Herdsman took a line unfavourable to his case. Mr. Herdsman supposed both the footwall and hanging walls of the iron-ore bodies to be metamorphosed sediments. De Launay, however, supposed the underlying and overlying porphyries of Kiruna to be surface lava flows, whilst, as Dr. Fermor had already pointed out in footnote 2 on page 113 of his paper, De Launay's explanation of the sedimentation of the iron ore itself referred to quite a different sort of sedimentation from that ordinarily understood by the term. The iron ore according to that explanation was of pneumatolytic-hydrothermal origin, having been emitted from a submarine lava flow as vapours of ferric chloride and sulphide. The foregoing was based on the account of De Launay's hypothesis as summarised in Stutzer's paper and in the work by Beyschlag-Krusch-Vogt already cited (page 272). It seemed to disagree with the quotation from De Launay given by Mr. Herdsman, and he (Dr. Fermor) could only suppose that the sedimentary rocks referred to in that quotation were the admittedly sedimentary (at least in part) Kurravaara and Hauki series, forming the foot and hanging walls of the porphyries. The meaning to be attached to "sedimentation" in that passage when applied to the iron ores was probably the pneumatolytic-hydrothermal one mentioned above.

In the next paragraph of Mr. Herdsman's remarks occurred the passage "including no doubt numerous intercalated sandstone beds," that was, intercalated in the supposed original clays and shales. But no remnants of original sandstone beds were now traceable in the hanging and footwall porphyries of Kiruna, so that Mr. Herdsman must suppose those original sediments to have been reduced to a state of such extreme fluidity that the original sandstones and shales became incorporated one in the other. Mr. Herdsman was, therefore,

¹ By that is meant "treated as a whole." Of course, Dr. Fermor admitted that some deposits of iron ore were of sedimentary origin.

postulating the admixture, whilst in a state of fusion, of adjacent beds of different composition, a result directly opposite to that obtained by magmatic differentiation. One might legitimately expect the original ferruginous sediments to share in that process, and to become admixed with the molten shales and sandstones with production of iron-silicate minerals, instead of suffering a natural refining process, as required by Mr. Herdsman's theory.

Even supposing there were sandstone layers intercalated between the hypothetical beds of shale and clay, the addition of that extra silica would not account for the differences already noted by him (Dr. Fermor) (p. 119) between the composition of the porphyries and any product one might expect to obtain by the metamorphism of shale and sandstone with the addition of further supplies of material from the ore-bed. Mr. Herdsman admitted that the Kiruna porphyries showed "all the characters of rocks solidified from fusion." Hence the chief difference of opinion seemed to be that Mr. Herdsman imagined a magma formed by the fusion of sediments, while he (Dr. Fermor) imagined one derived from plutonic sources. The chemical composition of the porphyries supported, he thought, the latter supposition.

The rocks of Gellivare, which Mr. Herdsman considered showed signs of less metamorphism than the Kiruna ores, showed him (Dr. Fermor), judging from microscopic examination, that they had solidified from fusion, and had been subjected to dynamic pressure, either after or during solidification. Assuming the latter alternative, the difference between the pressure conditions at Kiruna and at Gellivare might be expressed by saying that the rocks of Kiruna solidified from fusion under conditions of static pressure, whilst those of Gellivare solidified under conditions of dynamic pressure.

When Mr. Herdsman said that the "average phosphorus contents of these deposits (the magnetites) is everywhere from 1 to 2 per cent.," the word "everywhere" was taken by Dr. Fermor to imply that the averages were taken separately for separate parts of one deposit. He (Dr. Fermor) saw now that Mr. Herdsman really meant that the average for the whole of each deposit was 1 to 2 per cent. That was probably the case, judging from the published figures: but the fact that the phosphorus contents of various parts of the Kiruna deposit must vary from almost nil up to nearly 18 per cent. did not (if it meant anything one way or the other) support the idea that those phosphoric ores were of sedimentary origin, as in such a case a more uniform distribution of the phosphorus might have been anticipated.

Coming now to the titanium point, it would be seen that according to Geijer the TiO_2 contents of the syenitic group of rocks had no relation at all to that of the iron oxides, but that Stutzer referred to leucoxene borders to magnetite in the syenitic rocks. Those two statements were not mutually contradictory, as the larger portion of the TiO_2 was stated by Geijer to be present as sphene, and a very small proportion only as ilmenite. It was presumably the latter that had given rise to the leucoxene, and the implied association of a

small amount of ilmenite with the magnetite explained that certain small quantity of TiO_2 (0·15 to 0·8 per cent.) actually present in the Kiruna ores.¹

If, however, Mr. Herdsman wished to persist with his point that because the magnetite ore-bodies did not contain as much TiO_2 as he would have expected had they been formed magmatically from syenitic magmas, then clearly he would be unwise to include the ilmenite and titaniferous magnetite deposits as examples of metamorphosed ancient fluvial or marine concentrations, as he did in the final paragraph of his remarks, for, in the case of these titaniferous ores, there was every gradation from the enclosing gabbros or anorthosites to the central ore-bodies, which, by implication, Mr. Herdsman was prepared to admit as evidence of magmatic segregation.

¹ *Die Lagerstätten der Nutzbaren Mineralien und Gesteine*, p. 267.

THE ANNUAL DINNER.

THE Annual Dinner was held in the Great Hall of the Connaught Rooms, Great Queen Street, London, on Thursday, May 9, and was attended by over 400 members and their friends.

The chair was taken by Mr. Arthur Cooper, President, and among those present were: Mr. J. M. Robertson, M.P., Parliamentary Secretary to the Board of Trade; His Grace the Duke of Devonshire, Past-President; Sir Hugh Bell, Bart., Past-President; Sir Robert Hadfield, F.R.S., Past-President; the Right Hon. Lord Airedale of Gledhow; the Right Hon. Lord Glantawe of Swansea; Dr. W. C. Unwin, F.R.S., President, Institution of Civil Engineers; Mr. Percy Gilchrist, F.R.S., Vice-President; Sir William Ramsay, K.C.B., F.R.S., President of the British Association; Sir Edward Johnson Ferguson, Bart.; Mr. William Beardmore, Vice-President; Sir William White, K.C.B., F.R.S.; Mr. E. Schaltenbrand; Dr. E. Schrödter; Mr. W. B. Peat; Mr. W. Evans, Vice-President; Sir John S. Randles; the Rev. Dr. Gow, Head-Master of Westminster School; Lieut.-Col. P. G. Von Donop, R.E., Inspecting Officer of Railways, Board of Trade; Mr. A. Greiner, Vice-President; Mr. C. J. Bagley, Member of Council; Mr. R. A. S. Redmayne, H.M. Chief Inspector of Coal Mines; Mr. J. M. Gledhill, Member of Council; Mr. W. E. Garforth, President, Institution of Mining Engineers; Mr. Illyd Williams, Member of Council; Mr. Edward Hooper, President, Institution of Mining and Metallurgy; Mr. Francis Samuelson, Member of Council; Dr. Paul Goerens; Mr. A. Lamberton, Member of Council; Mr. Leslie S. Robertson; Mr. M. Mannaberg, Member of Council; General Leandro Cubillo; Mr. C. Vattier, Delegate of the Chilean Government; Mr. E. B. Ellington, President, Institution of Mechanical Engineers; Sir H. F. Donaldson, K.C.B., Chief Superintendent of Royal Ordnance Factories; Mr. J. Stephen Jeans; Mr. Arthur Balfour, Master Cutler of Sheffield; Sir A. Seale Haslam; Mr. J. A. F. Aspinall, and Mr. H. de Gorski.

The PRESIDENT gave the toast of "His Majesty the King" (Patron of the Institute), and of "Her Majesty Queen Mary, Queen Alexandra, His Royal Highness the Prince of Wales, and other Members of the Royal Family."

Mr. J. M. ROBERTSON, M.P., Parliamentary Secretary to the Board of Trade, proposed the toast of "Kindred Institutions." He said that it was in the enforced and regrettable absence of the President of the Board of Trade that he, as one of the humbler instruments of that Department, had the honour of proposing that toast. That Department had various and frequent intercourse with the various forms of industrial life in Great Britain, and the phrase "Kindred

Institutions" suggested to the mind all the developments and ramifications of that great industry for which the Iron and Steel Institute stood. It had been said by a German thinker that "The man who made the first wheel was the father of all machinery," but he assumed that the first wheel was made of wood, and machinery would have made but little progress unless iron had been introduced into its construction. The Institute was happily immune from politics, but perhaps it was capable of being brought into philosophic comparison with the political side of human life. If they made a broad comparison of modern civilisation with the civilisation of antiquity they were entitled to say that it developed mainly in two respects, politically and scientifically, and when he referred to scientific development he had in mind the application of science to the works of man. He supposed that, anthropologically speaking, man had been in the iron age for some thousands of years, but it was only in the latter phase of that age that he had really come into his kingdom. The iron age was the age of peaceful progress, and notwithstanding the manufacture of munitions of war, it was the great symbol of the peaceful conquest of nature. In speaking of kindred societies, he had in mind the great societies devoted to engineering, mining, and metallurgy the whole world over, whose members were the men who tunnelled mountains and pierced the sea, who constructed railways, planned great bridges, and built mighty ships. To speak of ships at that moment was inevitably to recall the *Titanic* disaster, of which they could only think as of an earthquake that had shattered a city. While under the shadow of that terrible disaster it was some consolation to recall the fact that in the ten years preceding that calamity British ships had carried across the Atlantic six millions of passengers with the loss of only nine lives. In regard to the trade of Great Britain, it was some satisfaction to know that even in the month in which the recent coal strike commenced, the trade of the country nearly maintained the great rise which it had been recently making, and but for the coal strike the figures would have been the best on record, independent of the fact that the figures of imports and re-exports for the month were the highest in the history of the country. He might be permitted to augur from that that the industrial outlook was satisfactory. The toast was coupled not only with the name of the President of the Institution of Civil Engineers, but with names associated with great foreign branches of the universal industry for which their Institute stood, and it might be fairly said that science spoke but one language for all mankind. He was reminded, and the fact was one which should make for goodwill among the nations, that the wonderful modern industrial development by one of the very greatest of the kindred nations was associated with a British invention, and it was a pleasant thought to him that it was a British invention, the Gilchrist-Thomas process, which underlay the great modern developments of the German iron trade. That being so, it was not too much to say that commerce was the great peace-maker in the world, and that it was commerce that drew men of

different nations together, and that while commerce was the peace-maker applied science was the universal benefactor. He gave them the toast of "Kindred Societies," associating that toast with the names of Dr. Unwin, President of the Institution of Civil Engineers; Dr. Ing. E. Schrödter, General Secretary of the Society of German Ironmasters; and Mr. A. Greiner, Past-President of the Liege Association of Engineers and Councillor of the International Testing Association.

Dr. W. C. UNWIN, F.R.S., President of the Institution of Civil Engineers, in responding to the toast, said that he had been selected for that duty as the President of the oldest of the Societies devoted mainly to applied science. Iron had now, of course, been deposed from the great position it held fifty years ago by its younger rival steel, although perhaps it would be more correct to call mild steel ingot iron. He could remember some of the last of the great wrought-iron bridges and the construction of some of the first steel bridges, and speculations might be indulged in as to the place which would be taken in the future by the new alloys of iron, in the production of which Sir Robert Hadfield had played so great a part. The real achievement of Great Britain in the last century had been the establishment of the great industrial system which had made society what it was to-day. He referred to the manner in which civilisation, as it was understood to-day, depended upon the utilisation of the energy stored up in our coal resources. Iron was required in generating and distributing that energy. It had been said that in the utilisation of the energy of coal the world had been made filthier. There was some truth in that, but with the further progress of science they might hope for less smoke. Of the kindred societies the earliest was the Royal Society, which was founded in 1660 by a few men gathered together by Sir Christopher Wren. The Royal Society concerned itself with the most recondite and fundamental problems of science, but in earlier days it took great interest, not only in pure science, but in the applications of science. It was interesting to remember that Savery's steam-engine was shown at the Royal Society in 1689, and as early as 1708 the Society concerned itself with a project for propelling boats by the agency of heat, and Robert Hope would very much have liked to put that project into practice, but was unable to do so for want of funds. The Royal Society in very early days took into its ranks the engineer Smeaton, thus showing its interest in applied science. Notwithstanding its royal patronage the Society suffered in its early days from want of funds. There were members who did not pay their subscriptions, and indeed Newton was excused the payment of his subscription by reason of want of means. It was characteristic of the Institution of Civil Engineers that it had included within its ranks members of every branch of the great engineering profession, and had contributed to the advancement of engineering during the whole of the last century. By having these men within its ranks, in stimulating research, in recording discoveries in its transactions, and in publicly discussing such discoveries, the Institution had contributed to the advancement of

science and its application. It would be impossible to over-rate the advantage of the work which had been done by the Institution of Civil Engineers and the group of societies to which it had given rise. There was a great field for the activity of such institutions, and that was in connection with research work. A great deal of research work had been done by private individuals and in the laboratories of works and factories, but there was a great deal of research which did not open up any prospect of any immediate return, and in work of that nature the kindred societies were now taking their fair share.

Dr. E. SCHRÖDTER, General Secretary of the Society of German Ironmasters, said it was his grateful task to speak on behalf of the German Ironmasters' Association. If for Germany the universal dream of peace should be realised, then the Iron and Steel Institute would be able to say that it had taken a prominent part in performing such humanitarian work. Speaking from the German standpoint, he believed that the election of Mr. Arthur Cooper as President was the best possible promoter of international friendship. His German friends sent a message of congratulation to the President, with their sincere wishes for the continued prosperity of the Iron and Steel Institute. He personally wished Mr. Cooper a successful period of office.

Monsieur A. GREINER, Vice-President, Past-President of the Liege Association of Engineers and Councillor of the International Testing Association, said he felt that it was a great privilege that his name should have been coupled by Mr. Robertson with those of other representatives of prominent kindred societies. The Associations with which he had the honour to be connected were proud to feel that they enjoyed the close friendship of the Iron and Steel Institute. The Association des Ingenieurs sortis de l'Ecole de Liege in particular was one of the oldest engineering societies, as it was founded as far back as 1842; and the International Testing Association carried on a work closely allied to that of the Iron and Steel Institute. As the name of that Association implied, its chief object was the study of practical methods of testing the physical and chemical properties of metals, so as to secure uniform international practice in the matter of testing. It needed no words of his to emphasise the advantage of being able to carry out tests upon a material in one country which would be comparable with those made in another, and in that respect the Association could justly claim to have accomplished much useful work. The Iron and Steel Institute had, he believed, twenty-four nationalities represented within it, and about the same number were represented in the International Testing Association, from which he thought it would be agreed that science recognised no boundaries of nationality or of race. They worked together not only for the good of the particular country to which they belonged, but for the advancement of scientific knowledge in the world at large. He had to thank Mr. Robertson for the very kind terms in which he had referred to the Association which he had the honour to represent.

Sir ROBERT HADFIELD, F.R.S., Past-President, in proposing the toast of "The Guests," said that the pleasure of proposing that toast was the greater owing to the number of distinguished men who were present that night. These included Sir William Ramsay; Dr. Unwin, the President of the Institution of Civil Engineers, the new building for which, he was glad to say, was making excellent progress; and Dr. Schrödter, whom they were all delighted to see from Germany. He had had an opportunity of inspecting some of the great works in Germany, and had been much impressed at the progress which was being made. He was sure, however, that Dr. Schrödter would forgive him for claiming that Great Britain, too, was still holding her own. They were glad to see present that evening their continental friends. He hoped Dr. Schrödter would take back to Germany from that gathering the certainty that there was no man present who did not wish to see good relations continue between Germany and England. Germany had great difficulties to face, and could not be blamed for making the same preparations that Great Britain had the right to do. He had had the pleasure of seeing, while in Berlin, some of the wonderful German scientific institutions, and only last week he had had the pleasure in London of meeting some of the leading German scientists. A visit was at the same time paid to Sheffield, and their German friends had expressed their pleasure at the progress being made in that great city. He wished to refer briefly to their new President, Mr. Cooper. Mr. Cooper was really a chip of the old block, for he came from Sheffield, and his Sheffield friends were glad to see him in the chair and to wish him every success. With regard to Sir William White, with whose name the toast was coupled, they were all aware of the good work he had done for the Institute. They also had present that night Mr. Robertson of the Board of Trade, and they all watched with great interest the work of that department, which was of great importance. Mr. Robertson had referred to the *Titanic*, and he (Sir Robert) might perhaps be allowed to say that it was no defect of material which caused that disaster, and that there was nothing wrong with the steel-work in that ship. It was the result of unfortunate circumstances, and they all sincerely hoped such a disaster would not occur again.

Sir WILLIAM WHITE, F.R.S., K.C.B., said it was the usual custom to begin a speech on behalf of the guests by speculations as to why the man whose name was associated with it had been chosen to represent distinguished visitors. He did not on that occasion propose to trouble them with any observations of that character; he was quite content to have the honour in that distinguished gathering of expressing to the President and members of the Iron and Steel Institute the gratitude which all the guests felt at being invited to that splendid banquet and for having such a pleasant evening. He was the more grateful because there was a time when he was a member of the Institute, but owing to the way in which the number of his subscriptions had increased he had taken the liberty of passing from the list of members to the outside, and now had the pleasure of

being present as a guest of the Institute, and should continue to come as long as an invitation reached him. It was a large order to represent the guests assembled there that night, distinguished men from many countries, men distinguished in many ways. One guest present that night, the President of the British Association, might have better performed the duty ; but perhaps they had fought a little shy of him, because he had been giving currency to an idea in regard to dealing with the coal deposits of this and other countries, which might not have been altogether well received by some members of the Iron and Steel Institute. He was, however, sure of this, that if Sir William Ramsay had risen and explained, in the attractive manner of which he was such a master, the great features of that scheme, it would have been much more interesting than anything he (Sir William White) could have to say. First of all, on behalf of foreign guests, he would like to say how much they appreciated the honour of being present that night ; and as the representative of the German iron-masters had said, meetings of that kind afforded a favourable opportunity for doing the wonderful work of bringing nations together in which the Iron and Steel Institute had played so great a part. He heartily endorsed what had been said on that head. Speaking for the home guests, they were also debtors to the Institute and were happy to have the opportunity of acknowledging the debt. If he might, he would like to express the pleasure it was to him to be there with Mr. Cooper sitting in the chair as President. Those who had had to with the great work of standardisation, which had been proceeding in Great Britain and throughout the world for many years, knew how excellent and valuable had been the assistance which had been given by Mr. Cooper in bringing closer together users and manufacturers of materials to the mutual advantage of both. They wished Mr. Cooper a most successful period of office, and they had the assurance that it would be so, because to high personal qualities was added a professional standing and distinction which ensured success. He would like to make one reference to a matter in which he had been able to play some part of late, and in which he hoped members of the Iron and Steel Institute would take an active interest in common with all English-speaking engineers throughout the world. When he was in the United States last November it was represented to him by those connected with engineering and the iron and steel industry that it was fitting there should be placed in Westminster Abbey a memorial window to a great man of science and engineer, Lord Kelvin. Lord Kelvin was buried in the Abbey, and they would hear from their Secretary very soon in a more formal fashion, that out of that suggestion which originated in the United States had come action which was being taken by the parent society, the Institution of Civil Engineers, which they believed and hoped would result in a memorial window being placed in Westminster Abbey to represent the reverence, affection, and esteem which all English-speaking engineers throughout the world felt for the memory of Lord Kelvin. There was a saying which he could not quote exactly, although he had

heard it used at a dinner of the Iron and Steel Institute by a master of eloquence, whom he did not pretend to emulate. Speaking of the widespread influence of the Iron and Steel Institute and of the many friendships which had grown up under its shadow, he ended by hoping that the phrase, "Grapple them to your hearts with hoops of steel" would always remain the motto of the Iron and Steel Institute.

Mr. W. B. PEAT proposed the toast of the Iron and Steel Institute. He said that through the courtesy of the President and the Secretary he had been invited to fulfil a somewhat difficult task under any circumstances—namely, to propose the toast of "The Iron and Steel Institute." He said "difficult under any circumstances," but he was encouraged by the remark once made by an eminent man in the steel trade that "a preacher who could not strike oil in ten minutes had better cease boring." He fully appreciated the honour which had been conferred upon him, the importance of which was measured by the fact that in proposing that toast, great names, such as Lord Alverstone, Duke of Norfolk, Lord Justice Fletcher Moulton, Sir Edward Grey, the late Lord Airedale, and Sir H. Llewellyn Smith of the Board of Trade, had been associated. If he attempted to attain to the standard of any one of the speeches which were delivered on those occasions he would lamentably fail, and further, it would be impossible for him to approach the subject with the knowledge of affairs which any one of those gentlemen possessed. But he had the advantage in addressing them of being able to say that he was a looker-on with such knowledge as figures could give of the industry in which the Institute was interested; and he claimed that in such a case the looker-on saw a good part of the game, and perhaps the most interesting part—the periodical results. The Institute was founded nearly two generations ago by men who enjoyed the appreciation, and he might almost say the affection, of their fellow-men. Such men as Sir David Dale, Sir Lowthian Bell, and William Whitwell, while not seeking to curtail the commercial individuality of those engaged in the steel and iron trade, conceived the idea of giving to the world all the benefits which flow from the elucidation of new systems of manufacture. The whole world was the stage on which they desired that the Institute should play its part, not seeking for the benefit of any one works or any one country; and wherever the iron and steel trades had an existence—which in those days might be from Greenland's icy mountains to India's coral strand—there it was their intention to spread the advantages of modern scientific methods. The policy founded and incorporated in the Institute was no selfish policy; no country and no individual was to be poorer from its operations. Everybody of every country in every branch of industry in the steel and iron trade was to be benefited. The founders were furthest removed from:

"The good old rule and simple plan,
That he shall take who has the power,
And he shall keep who can."

If a layman might venture a suggestion, it was that the Institute could, with advantage, travel still further on the lines of international co-operation towards attaining the ends contemplated by those founders of the Institute, who wisely foresaw that insular seclusion was not good for any country, and that the whole world might become the theatre of the Institute's beneficent operations. Institutes and associations did not live by conjuring with the names of those who, in bygone days, built them up; and he claimed on behalf of that Institute that the policy of its founders had been amply fulfilled by the wise men who now controlled its destinies.

Great Britain had always been represented on the Council of the Institute by the greatest minds engaged in the steel trade, to say nothing of the eminent scientists of all nations who were amongst the rank and file of membership. Austria was represented on the Council by Mr. Kestranek; Belgium by Mr. Greiner, than whom no one held a warmer corner in the hearts of those directing the destinies of the industry; France by Mr. Schneider of the Le Creusot works; Germany by Dr. F. W. Lümann and by Mr. Springorum, the eminent President of the German Society of Ironmasters; Italy by Mr. G. E. Falck, President of the Italian Metallurgical Association; Sweden by Mr. E. J. Ljungberg, the Director of the largest mining company in Sweden; and finally, the United States of America was represented by Mr. Andrew Carnegie and Mr. John Fritz, names familiar to the iron and steel industry all the world over. Out of a total membership of well over 2000, there were representatives of no fewer than twenty-four distinct nationalities.

No greater gathering of men who had made their mark in the greatest of the world's industries could be found than that assembled there that night. The international character of the Institute was distinctive and unique. There was hardly an invention which had formed an important epoch in the progress of the steel trade, which had not in the first place been brought to light in the records of the proceedings of the Institute. Among those he would refer to the Siemens process, on which a paper was read by Sir William Siemens in 1873. At the present moment it was not a wild statement to make that close on 35 million tons of steel per annum were made by the open-hearth process. Then there was the Thomas-Gilchrist process upon which a paper was read by Mr. Thomas in 1879, and although Mr. Thomas was no longer living, Mr. Gilchrist, his co-inventor, was present that night. That process rendered possible the utilisation of millions of tons of phosphoric iron ore; created wealth out of poverty, and made barren places teem with population and ring with prosperity.

In the domain of manganese steel a paper was read in 1888 by Sir Robert Hadfield, who was the inventor of that alloy, and who was also present that night. He would also refer to the open-hearth continuous process, upon which a paper was read in 1900 by Mr. Benjamin Talbot, like Sir Robert, a Bessemer medallist, and also present with them. He might extend the list, but he had done enough to remind them that the policy of the Institute for two generations had been

co-operation in the utilisation of every useful invention. If he ventured to trouble them for a moment longer, it was merely to touch on a problem affecting the steel and iron trade, which was common to every country and affected every manufacturer in every country more or less directly (and no less important to the well-being of the industry than the inventions to which he had referred), and that was the unrest in the labour world. What use could be made of the directing brain of a great industrial enterprise, and the moneys of the investing public which had been put into it, unless there was accorded that third support which made the whole useful, namely, a reasonable supply of labour on reasonable terms. It was not as if unrest in the labour world affected one country and escaped others, but there was a growing solidarity of labour, evidenced by the fact that in the recent strike labour delegates from Germany and France and from other countries visited England to confer with those directing the strike. It did not appear that the industrial unrest was altogether a question of wages; it had been well said that the toe of labour was close on the heels of capital, and encroaching on its very existence. He recalled the fable of the frog, whose attenuated limbs held a conference and decided to claim a greater share of the good things which the head and body seemed to retain. No possible solution presented itself—the limbs could not act alone nor could the head and body; and starvation alone brought those parts of the whole to realise their mutual dependence each on the other. Whether labour unrest was dealt with by co-partnership, by sliding scales based upon the value of products, or by the old-fashioned method of fighting to a finish; whether capital submitted to demands—perhaps unreasonable and perhaps made without due regard to the interests of industry; or whether it might be considered better to admit that the relations of labour and capital were as much a common feature of the common industry as the inventions upon which it based its prosperity, and discuss them accordingly, were matters upon which he did not feel himself called upon, or indeed capable of, expressing an opinion. That matter, which overweighed all others in its importance, was already in the minds of the governments of all the nations of Europe. To the President was entrusted the task of navigating the Institute along the channels which its founders had constructed, and of continuing a policy of co-operation and good-fellowship with the citizens of every country engaged in the iron and steel industry, giving and getting the best products and the brains and the skill, of which no one country could claim the monopoly. The President's achievements in the trade in which the Institute was interested needed no comment, for they were known wherever the steel trade was known. Mr. Cooper was a Bessemer metallist of twenty years' standing, the foundations of the commercial application of the Thomas-Gilchrist process were largely encouraged by him, and he was one of the pioneers of that branch of industry. He believed that the Institute was happy in the selection of its President, and he believed that Mr. Cooper would follow worthily in the footsteps of the giants who in past times had

held sway over the destinies of the Iron and Steel Institute. He had great pleasure in proposing the toast of the Iron and Steel Institute, and in coupling with it the name of their President, Mr. Arthur Cooper.

The PRESIDENT, in reply, said that, as Mr. Peat had remarked, the Iron and Steel Institute was an International Association. It was true its headquarters were in Great Britain, but twenty-five per cent. of its members hailed from the chief iron- and steel-making centres in the continents of Europe, America, and Asia, and, as Mr. Greiner had pointed out, the members belonged to no fewer than twenty-four nationalities. He was convinced that the colonial and foreign membership was a source of great strength to the Institute, because no country could claim to have a monopoly of the brains of the world, and it was only by the free interchange of opinions between men who were occupied in solving the great problems which confronted the industry in different parts of the world under different conditions that the best results could be achieved. He believed that the Iron and Steel Institute had done much to break down the prejudice which formerly existed in the minds of many and caused them to withhold from competitors any information. It was now generally accepted that the free interchange of ideas and opinions among competitors resulted in mutual benefit. That constituted a sufficient reason for welcoming accessions to their colonial and foreign membership; but there was another reason. Mr. Peat had referred to former proposers of the toast of the Iron and Steel Institute, and he would like to refer to one name which Mr. Peat had omitted to mention; it was that of His Excellency Lord Strathcona. A few years ago, in proposing the toast, Lord Strathcona said that he hoped by means of iron and steel the Empire would be more closely knitted together. He would go a step further; he believed that by means of iron and steel not only the Empire but all the iron and steel making nations of the world would be more closely knitted together, and that thus the Iron and Steel Institute might assist in the permanent establishment of friendship and goodwill throughout the world. He only desired in conclusion to thank Mr. Peat for the eloquent way in which he proposed the toast and those present for the kind way in which they had received it.

O B I T U A R Y

MR. WILLIAM HENRY BLECKLY, Honorary Treasurer of the Iron and Steel Institute, and a trustee of the Bessemer Medal Fund, died on the morning of Tuesday, July 2, at the Pwllcrochan Hotel, Colwyn Bay, at the age of seventy-one years. He had been somewhat poorly for some months, and had been staying in North Wales in the hope of regaining his health. By his death the Institute has suffered a severe loss, as throughout his whole connection with it he evinced the greatest interest in its affairs, was assiduous in his attendances both at council meetings and general meetings, and devoted to the promotion of its interests ungrudging time and labour. He was an original member, having joined the Institute together with his brother, Mr. John James Bleckly, as far back as 1869, the date of its foundation.

Mr. Bleckly was born in 1840 at Northallerton, and was the eldest son of the late Mr. Henry Bleckly, the chairman of the Liverpool Quarter Sessions, and for several years chairman of the Warrington Board of Guardians, and Mayor of the town. He was educated at Queenwood College, Hampshire, an establishment founded originally by Robert Owen, and subsequently converted, in the year 1847, into a school, famous for having numbered amongst its scholars the late Henry Fawcett, Professor Tyndall, and several other men who have achieved note. Mr. Bleckly left school early, and joined his father at Dallam Forge in 1856. At that time the Lancashire iron trade was comparatively speaking in its infancy, but a period of prosperity was before it, and with that prosperity Mr. Bleckly was, for many years, closely and directly associated. In addition to Dallam Forge, his father acquired Bewsey Forge, and subsequently the collieries of Messrs. Pearson & Knowles, with which the forges were amalgamated, to become, in the year 1874, the Pearson & Knowles Coal and Iron Company, Limited. The iron and steel departments of these works have an output of 2500 tons finished iron and steel per week, and employ over 2000 hands, apart from those employed in the colliery itself. Mr. Bleckly was for many years managing director of the Company, and was associated, in his direction of its affairs, with his brother, the inventor of the repeating wire rolling-mill, which was installed in the works at Warrington, and has since been largely adopted both at home and abroad.

In politics he was a Conservative, and, although he took little active part in public affairs, he was an accomplished and convincing speaker, and was always listened to with interest and respect. He was imbued with literary tastes, which led him to amass a valuable collection of works at his home at Thelwall Lea. He was also an

ardent sportsman and an excellent shot. In Warrington he was most highly esteemed, and his philanthropic nature led him to bestow many benefactions upon that city. As a business man he was punctilious in the extreme, but, while assiduous in the discharge of his duties, he imported into their discharge kindness of heart, tact, and discretion. By his colleagues on the Council of the Iron and Steel Institute, to which he was elected in 1881, his opinions were highly valued, and his advice frequently sought. In 1894 he was appointed a vice-president, and in 1900, on the election of the late Mr. William Whitwell to the presidency of the Institute, Mr. Bleckly was unanimously appointed honorary treasurer. In 1905 he succeeded the late Sir Lowthian Bell as co-trustee, with Sir David Dale, of the Bessemer Memorial Fund of the Institute. He also, from time to time, made valuable presentations of books to the library.

He was a director of Messrs. Ryland Brothers, Limited, deputy-chairman of the Pearson & Knowles Coal and Iron Company, Limited, and a director of the Partington Steel and Iron Company, Limited. He also served for many years as a governor on the Court of the University of Liverpool.

He married the youngest daughter of Mr. John Johnson, of Easingwold, near York, who survives him, and by whom he had three sons and one daughter. Mr. Bleckly was buried on Friday, July 5, at Thelwall Church, the funeral being attended by the President of the Institute, Mr. Arthur Cooper, and by several members of the Council.

SIR JOHN GAY NEWTON ALLEYNE, Bart., of Chevin, near Belper, died at Falmouth on February 20, at the age of ninety-one. He was born at Barbadoes on September 8, 1820, and was the son of Sir Reynold Abel Alleyne, Bart. Though the baronetcy was created as far back as 1769, Sir John, who succeeded his father in 1870, was only the third holder of the title.

He was educated at Harrow and at the University, Bonn; and from 1843 to 1851 was warden at Dulwich College, to the family of the founder of which his own family claimed to be related. His business career commenced with a short engagement at Barbadoes in the sugar industry, after which he entered the service of the Butterley Iron Works Company in Derbyshire.

One of the first manufactures which engaged Sir John (then Mr.) Alleyne's attention was that of rolled iron girders for floors, and deck beams for iron ships. In 1853 Messrs. Fox & Barrett introduced their system of fireproof flooring, for which the Butterley Company supplied the rolled girders or joists. An enormous demand arose, and the capabilities of the mills then in use were soon exceeded, but Mr. Alleyne introduced his system of welding which enabled the largest sections to be produced without unduly taxing the capacity of the comparatively small rolling-mills then in operation. Sections of T-iron were rolled, and by welding two of these together an H-section was formed. For still deeper sections a piece of boiler

plate was inserted between the T-bars, so that there were two longitudinal welds instead of one. Great difficulties were met with in the welding process, but the skill and perseverance of Mr. Alleyne overcame them; and the method finally adopted proved exceedingly effective.

In the Exhibition of 1862 the largest exhibit in iron and steel was that made by the Butterley Company; every item in which exhibit was made under the personal supervision of Mr. Alleyne. It may be interesting at this date to name a few of the specimens out of many:—A solid deck beam 16 inches deep, with knees welded in. A solid wrought-iron engine beam 31 feet 9 inches long by 7 feet wide, $2\frac{3}{8}$ inches thick, weighing 7 tons. An armour plate, 14 feet long, 5 feet wide, $4\frac{1}{2}$ inches thick. A solid welded wrought-iron girder, 3 feet deep, with flanges 12 inches wide, and another similar girder 2 feet 6 inches deep.

In consequence of wrought iron proving unequal to resist the fire of improved guns, the manufacture of iron armour plates was not proceeded with, but Government orders for deck beams, chain iron, &c., were such, that for many years two Admiralty inspectors resided near the works to carry out their duties in connection with the firm's Government contracts.

The Bessemer and other processes for cheap steel had not been introduced when Mr. Alleyne turned his attention to manufactures in iron; and owing to the increasing difficulty of obtaining good puddlers, in 1867 he devised a puddling furnace with a rotating circular bottom combined with a reciprocating mechanical table. This furnace was shown working at Colnor Park in 1870.

In that year Sir Reynold died, and Mr. Alleyne succeeded to the baronetcy; in the same year he designed and constructed the splendid two-high reversing-mill for rolling iron and steel girders and deck beams up to 16 inches deep, fitted with traversing tables, movable saws, and other appliances which only appeared at a much later date at other works. Many schemes for reversing rolls had been publicly discussed, and Sir John adopted the bold and novel expedient of two independent engines fitted with heavy fly-wheels, which alternately drove the mill in either direction as required; and as the reduction in speed during each pass was recovered by one engine whilst the other engine was driving the rolls, the output of the mill was increased considerably. Although this arrangement was afterwards improved upon by reversing engines, this mill worked with success and economy.

In 1868 the Butterley Company secured the contract for the large roof of St. Pancras Station, London; and as no roof of so large a span and of similar design had been then erected, the masterly way in which the manufacture of this roof at the works, and the still more difficult problem of its erection on the site, were carried to completion, is in itself a striking testimony to the originality and resource of Mr. Alleyne. It has a span of 240 feet, springing from rail level to a height of 102 feet, with twenty-four main ribs weighing about

60 tons each, for the erection of which Mr. Alleyne designed two large timber stages, each made in three divisions, running on wheels so that each part could be moved independently, fitted with power-driven hoists for lifting the ironwork into position, and on these stages pairs of ribs with intermediate purlins were erected; and when one pair was completed the stages were moved forward for the erection of the succeeding pairs. This system of erection has been followed by other contractors in similar cases.

In 1872 the Butterley Company undertook the manufacture and erection of the large double-line railway bridge over the Old Maas at Dordrecht, consisting of four fixed spans varying in length from 283 feet 10 inches to 211 feet 9 inches, and two double openings respectively 167 feet 4 inches and 105 feet wide, crossed by swing spans. This was a heavy and difficult work; and again were the remarkable skill and foresight of Sir John evidenced in his arrangements for the design of the staging and tackle and the erection of the ironwork. The bridge remains to this day as a splendid example of good material and workmanship.

Nor were his labours confined to practical everyday work. He was a skilled astronomer, having a well-fitted observatory; and the method of determining small quantities of phosphorus in iron and steel by means of the spectroscope, as devised by him, placed him in the front rank of those who have enriched science by physical research. The products of his private workshop bore evidence as to his technical skill, and few workmen could handle tools better than he did.

Sir John Alleyne contributed a paper on "The Estimation of Small Quantities of Phosphorus in Iron and Steel by Spectrum Analysis" to the Iron and Steel Institute.¹ He was a member of the Institution of Civil Engineers and the Institution of Mechanical Engineers, and was one of the original members of Council of the Iron and Steel Institute, having been subsequently elected a vice-president in 1870. He married in 1851 Augusta Isabella, the daughter of Sir Henry Fitzherbert, by whom he had one son, Reynold Henry Newton Alleyne, who predeceased him. Lady Alleyne died in September 1911. His eldest grandson, John Meynell Alleyne, a lieutenant in the Royal Navy, succeeds to the baronetcy.

WILLIAM ALLOTT died at Chapeltown, Sheffield, on May 18, 1912, aged sixty years. He was managing director of Newton Chambers and Company, Limited, of Thorncliffe. Born in 1852, he received his education at Barrow, Wentworth. He started his business career in the collieries, and was afterwards promoted to a post in the office of the Company. Upon the death of Mr. Chambers, the directorate showed their confidence in him by entrusting him with the full management of the whole of the Thorncliffe mining properties, and later elected him to a seat on the board, and eventually managing director. He was elected a member of the Iron and Steel Institute in 1905.

¹ *Journal of the Iron and Steel Institute*, 1875, p. 62.

ADAM CARLISLE BAMLETT died on January 10, 1912, at his residence, Sowerby, Thirsk, aged seventy-six years. It is rather more than half a century since he laid the foundations of what developed into an important agricultural engineering business. In 1854 he built some small workshops which gave employment to about a dozen men. His products had not been on the market long before they began to attract the attention of agriculturists, and they quickly came into considerable vogue. The works at Thirsk had to be extended in order to cope with the steadily increasing demand, and they were gradually developed until at the present time they give employment to over 200 men. Of late years his attention was chiefly devoted to the various processes of tar-spraying and the laying of tar-macadams, and he established a plant of his own for the manufacture of material. He was a member of the Institution of Civil Engineers, of the Institution of Mechanical Engineers, and of the Sanitary Institute. He was elected a member of the Iron and Steel Institute in 1877.

Mr. GUSTAVE BOËL died, at the age of seventy-five years, at his residence at Brussels, on Sunday, March 31, as the result of a short illness. He was born at Houdeng-Goegnies on March 18, 1837. He had been a Senator of the Belgian Upper Assembly from the year 1880 to the time of his death, and had sat as recently as March in the current year. He was the owner of a number of important industrial concerns in Belgium, including sugar refineries, an ice factory, and ironworks and collieries in the Chenoy district. In the earlier days of his career, he was associated with the late Mr. Boucqueau in a number of important undertakings. The fortunes of the firm being jeopardised by a financial crisis, Mr. Boël placed at the disposal of the Company his entire financial resources, and when, a few years later, Mr. Boucqueau died, he appointed Mr. Boël his sole heir, leaving to him the numerous activities which they had conjointly pursued. In politics Mr. Boël held strong Liberal opinions. He was a member of a number of learned societies and institutions in France and Belgium, and he was elected a member of the Iron and Steel Institute in 1892. He was buried at La Louviere on Tuesday, April 2.

GEORGE HENRY DAVEY died on September 8, 1911, at his residence, Woodside, Briton Ferry, Glamorganshire, at the age of seventy-three. He was a son of the late George Davey, who, in conjunction with others, built and started the Briton Ferry Iron Works in 1846. The deceased was educated at Sidcot School and at Worcester. Entering the Briton Ferry Works in 1854, he became manager in 1866. In 1889 the works were reconstructed, and the present Company, known as the Briton Ferry Works, Limited, formed; the deceased being chairman of directors, which office he retained until his death. The deceased was also for many years chairman of directors of the Villiers Tinsplate Company, Briton Ferry, and was connected with other local industries. He did not take a very

active interest in politics, but was a Conservative in his views. For many years he took a part in public life and was chairman of the Briton Ferry Local Board from 1870 to 1889. From 1894 until his death he was the chairman of the bench of the Port Talbot Petty Sessional Division. He was elected a member of the Iron and Steel Institute in 1871.

SIR THEODORE FRY, Bart., M.P., died on February 5, 1912, at his residence at Beechhanger Court, Caterham Valley, Surrey, in his seventy-seventh year, and was buried on February 8 in the Parish Cemetery of St. Mary's, Caterham. He belonged to a well-known north-country family, for many years connected with the Cleveland iron trade. The late Sir Theodore Fry was the second son of the late Mr. Francis Fry, of Tower House, Bristol, and of Matilda, the daughter of Daniel Penrose, of Co. Wicklow, and was born on May 1, 1836. It had been the intention of his parents that he should be especially fitted for trade and commerce, and he early developed a comprehensive grasp of these subjects. He received his education in Bristol. He went to Darlington in 1866, becoming chief partner in Fry, P'Anson & Company, Limited, Rise Carr Rolling Mills, which was succeeded in turn by Sir Theodore Fry & Company, Limited, of which company he was, until recently, chairman. He was, in addition, a director of the Bear Park Coal and Coke Company, Limited; a director of the Weardale and Shildon Water Company; of Saddler & Company, Limited; of the Nitrate Producers' Steamship Company, and latterly a director of Ruston, Proctor & Company, Limited, Lincoln.

At the age of twenty-six he married Sophia, daughter of Mr. John Pease, of East Mount, Darlington, and Cleveland Lodge, Great Ayton, Yorkshire, and grand-daughter of Mr. Edward Pease, by whom he had four sons and three daughters. She died in 1897, and in 1902 he married Florence, the eldest daughter of Mr. William Bates, of Oakdene, Birkenhead, by whom he had one daughter.

He was a great traveller and a collector of antiquities of various kinds. He was a Fellow of the Society of Antiquaries and a life member of University College, London. He was also a Doctor of Laws (*Honoris Causa*) for the University of Durham, and Lord of the Manor of Cleasley in the North Riding of Yorkshire.

In politics he was a Liberal, and from 1880 to 1895 he represented Darlington in the House of Commons. He was created a baronet of the United Kingdom in 1894, and is succeeded by his eldest son, Mr. John Pease Fry, born February 26, 1864. He was an original member of the Iron and Steel Institute, but resigned his membership on account of his advancing years in 1909.

WILLIAM BEALEY HARRISON of Aldershaw, Lichfield, died on March 25, 1912, in his seventy-fifth year. He was chairman of William Harrison, Limited, of Brownhills Collieries, Walsall, John Russell & Company, Limited, of the Alma Tube Works, Walsall, and

for many years a member of the Mining Association of Great Britain. He was elected a member of the Iron and Steel Institute in 1882.

WILLIAM EDWARD HIPKINS was drowned in the *Titanic* disaster on April 15, 1912. He was the only son of Mr. G. F. Hipkins, steel toy manufacturer, of Birmingham, and was born about sixty years ago. His early experience was gained in travelling abroad. On his return he undertook the management of his father's business, but subsequently disposed of the concern to become managing-director of J. & E. Wright, rope manufacturers, and in 1896 he undertook a similar position in the firm of W. & T. Avery. Here he was responsible for the entire re-organisation of the business of the firm, and particularly for the arrangements connected with its removal from West Bromwich to the famous Soho Foundry. He was a member of the Institution of Civil Engineers and the Institution of Mechanical Engineers, and was elected a member of the Iron and Steel Institute in 1895.

Baron HIPPOLYTE D'HUART died on February 23, 1912, after a very brief illness. He was a native of the town of Longwy, where he was born in August 1842. During the early part of his career he managed, jointly with his brother, Baron Fernand d'Huart, a blast-furnace which had been erected at Longwy by their father, and he was also interested in an important porcelain works in that neighbourhood. In 1883, with the assistance of the Société des Hauts Fourneaux de Maubeuge, the brothers founded at Longwy-bas the Société Métallurgique de Senelle-Maubeuge, of which they became the managers. In 1902 the former Company was taken over and amalgamated with the Société Métallurgique de Senelle-Maubeuge, and six years later Baron Hippolyte was appointed chairman of the board of directors. Under his energetic influence the Company developed very rapidly, and soon became one of the principal steelworks in Meurthe et Moselle. He was also one of the founders of the Société des Aciéries de Longwy and of the Société des Hauts Fourneaux d'Athus, of which he was a director.

In addition to his connection with the above mentioned Companies, he was chairman of the Société des Mines de Jarny, of the Société des Mines de Murville, and of the Association Coopérative Zélandaise de Carbonisation. He was also a director of the Comité des Forges de France; of the Banque de France; of the Comptoir Métallurgique de Longwy; and of the Société Lorraine de Carbonisation, at Auby.

Baron d'Huart was a powerful personality among the men connected with the iron industry of Lorraine, to the prosperity of which he largely contributed by his untiring enterprise and breadth of view. He also took an active part in the affairs of his native city, which loses in him one of its most distinguished citizens. He had served as a member of the Municipal Council of Longwy since 1876, and the Cross of the Legion of Honour was conferred upon him in recognition

of the numerous public services rendered by him during his long career.

Baron Hippolyte d'Huart was elected a Member of the Iron and Steel Institute in 1909.

JONATHAN LONGBOTHAM died on November 21, 1911, at the age of sixty-one years, at his London residence, Harescombe, Northwood, Middlesex. He was a native of Durham, and his professional training was acquired at one of the largest collieries in that county. From there he went to Norley Colliery, near Wigan, where he remained for a number of years. He next received the appointment of general manager of the collieries of the Barrow Hematite Steel Company at Worsboro'. For some years he was consulting engineer for the southern division of the North-Eastern Railway, and at the same time he carried on a considerable private practice as a mining engineer. He went to Sheffield ten or twelve years ago, and started a private practice as a mining and civil engineer. He was a member of the Institute of Civil Engineers, and was elected a member of the Iron and Steel Institute in 1898.

JOHN McCULLUM died at Santon Cottage, Scunthorpe, on March 26, 1912, at the age of sixty-two. For upwards of thirty years he was the general manager of the Appleby Iron Company Limited, of Scunthorpe. He had taken a prominent part in the development of the Lincolnshire iron industry, and was a member of the Lincolnshire Iron Masters' Association. He was elected a member of the Iron and Steel Institute in 1890.

WALTER STOWE BRIGHT M'LAREN, M.A., M.P., died at his residence, Great Comp, Borough Green, Kent, where he had been staying preparatory to journeying to Switzerland for the sake of his health, on Saturday, June 29, 1911, aged fifty-nine. He was the youngest son of the late Mr. Duncan M'Laren, of Edinburgh, who was Lord Provost, and for many years member for the City of Edinburgh, by his third wife, Priscilla, daughter of the late Jacob Bright and sister of John Bright. He was a half-brother of the late Lord M'Laren, and brother of Lord Aberconway. He was educated at Craigmount School, Edinburgh, and at the University of that city, where he graduated as a Master of Arts in 1873. In association with Sir Swire Smith he commenced business in Keighley as a worsted spinner, in the firm of Smith & M'Laren, but retired from the partnership in 1890. During his association with Keighley he displayed considerable interest in educational matters, and his firm took an active part in affording special facilities to the younger hands employed for attending evening classes in the town.

His father's association with politics and his mother's interest in political matters, and, in particular, her active advocacy of the cause of Woman's Suffrage, early directed his mind into the same channels. He joined the Men's League for Woman's Suffrage, of which he

eventually became a vice-president. He was an advanced Liberal and a strong Free Trader. His first attempt to enter Parliament was in 1885, when, at the age of thirty-two, he unsuccessfully contested Inverness Burghs. The following year he was elected for Crewe, which he represented until 1895, when the Hon. R. A. Ward captured the seat for the Unionists. Mr. James Tomkinson regained it for the Liberal Party in 1900, and on his death in April 1910, Mr. M'Laren was elected by a large majority. In December of the same year he was re-elected by an increased majority.

As an employer Mr. M'Laren was a firm believer in conciliation in industrial disputes, and took rather a prominent part in the Miners' Conciliation Board when it was set up, and he was one of the coalowners who took part in the recent negotiations with the Government and the miners which resulted in the Minimum Wage Act. His health suffered indeed somewhat severely owing to his exertions as a representative of the employers during the recent coal strike, while his defence of the South Wales coalowners caused trouble among his supporters at Crewe, and he was much distressed by the attacks which were made upon him. Standing, as he did, for a great industrial constituency, containing a large number of exceptionally intelligent voters, Mr. M'Laren's policy on such matters as employers' liability was often hotly discussed. He was opposed from the outset to the general principle of contracting-out. His personal popularity in Crewe was, however, unquestionable. He was a brilliant and impressive speaker, and possessed an engaging personality.

He had a peculiarly wide connection with the iron, steel, and coal trades of Great Britain, and was on the board of a considerable number of companies engaged in the manufacture of iron and steel, and was also on the board of the Madras Electric Railways (1904), Limited. He was a director of Bolckow, Vaughan & Company, Limited, and was also a director of the Dinnington Main Coal Company, Limited; the Sheepbridge Coal and Iron Company, Limited; the Tredegar Iron and Coal Company, Limited; the Maltby Main Colliery Company, Limited; the Oakdale Navigation Collieries, Limited; the Dunderland Iron Ore Company, Limited; the Brecon and Merthyr-Tydfil Junction Railway Company; the Cleveland Salt Company, Limited; the Soria Mining Company, Limited; the Electric Construction Company, Limited; James Dunlop & Company, Limited; the Madras Electric Railways (1904), Limited; the North American Land and Timber Company, Limited; and the National General Insurance Company, Limited.

He was a member of the Society of Friends. He was elected a member of the Iron and Steel Institute in 1898.

Mr. M'Laren married, in April 1883, Eva, the youngest daughter of Mr. William Müller, of Hillside, Shenley, Herts, and Valparaiso, Chile. His wife was well known for her work for the Liberal Party.

WILLIAM GREGORY NORRIS died on November 11, 1911. He was

born at Coalbrookdale in 1829, being the only surviving son of the late William Norris. He entered the service of the Coalbrookdale Company in 1848, and was made general manager in 1868. In 1881 he was made managing director, and remained a director of the Company until the close of his life. It may be of interest to recall the fact that some of the earliest wrought-iron boiler plates used in shipbuilding were made by the Coalbrookdale Company, and rolls were cut by hand about the year 1850 for rolling chequered plates, and samples of these were exhibited in the 1851 Exhibition in London. Mr. Norris always took a keen interest in all these early enterprises. For many years he had devoted his very extensive legal and business knowledge to helping in a most efficient manner all public or philanthropic work of the district and county, and he was especially interested in all educational matters and gave most liberally of his time and money to the support and help of local institutions. He was an original member of the Iron and Steel Institute.

General SALVADOR DIAZ ORDOÑEZ¹ died on October 14, 1911, from injuries received during the battle of Izmarufen, in Morocco. He was born in Oviedo on March 15, 1845. In December 1859 he entered the Military College at Segovia, and on the completion of his studies, in January 1866, he was appointed first lieutenant of artillery. He served in several regiments and distinguished himself during the Carlist Civil War, from 1872 to 1876, being honoured with various distinctions on account of his brilliant services. In 1879 he received an appointment at the Royal Ordnance Works at Trubia, where he remained for five years, until his promotion in 1884 to the rank of major. During the time he was at Trubia he was in charge of the Gun Factory, and devoted his time to the study of explosives and to the construction of guns. In 1881 he designed a 15-centimetre cast-iron tube gun, of which a large number were made at Trubia for various fortifications in Spain. He returned to Trubia in 1887 and continued his work in the development of new types of coast guns and Howitzers of 21, 24, and 30 centimetres calibre. These new guns were also of cast iron, fitted with steel tubes. In 1890 he advanced to the rank of lieutenant-colonel and remained at Trubia until April 1895, when, at his special request, he was ordered to Cuba. There he saw much active service and was also employed in various commissions of a technical nature. In 1897 he became colonel, and in the war with the United States he commanded the Artillery at Santiago di Cuba, where he was wounded on July 1, 1898. In consequence of his distinguished conduct on the battlefield, he was promoted to the rank of brigadier-general, and on his return to Spain he was placed in command of the Artillery in several military districts, notably in Madrid. He was also appointed President of the Technical Committee of Artillery and held the command of the fortress of Jaca. At the

¹ The Secretary is indebted to General Leandro Cubillo, Commander of Artillery in the district of Valladolid, Spain, for this biography.

same time he was closely occupied with his technical studies, working out calculations for a new 24-centimetre gun, L.45, and a new Howitzer of the same calibre. The latter has recently been approved after prolonged and severe trials. In 1908 he was promoted to the rank of major-general and was appointed Military Governor of Cartagena. In May 1910 he obtained the command of the Division which was centred in Melilla, in Morocco, and from the commencement of hostilities, in September 1911, he was at the front. On the 12th of that month he commanded his troops with conspicuous success in the engagement of Izmarufen, in which the Moors lost heavily. He occupied the positions at Izhafen and Izmarufen. He was just about to mount his horse for the purpose of paying a visit of inspection to this latter place, on October 14, when he was twice fatally wounded in the breast. General Ordoñez was an exceptionally learned man, a hard worker, and extraordinarily devoted to the study of everything connected with Artillery. He was of an exceedingly modest disposition, working without thought of personal reward but only for the benefit of his country. General Ordoñez was never married, and is survived by his two brothers, still living at Oviedo. He was elected a member of the Iron and Steel Institute in 1887, and it will be within the recollection of members that he attended the Autumn Meeting of the Institute held at Buxton in September 1910 under the presidency of the Duke of Devonshire.

FLORIS OSMOND died on June 18, 1912, at his residence at Saint-Léu, in the Department of Seine-et-Oise, France, at the age of sixty-three years. By his death the Institute has to deplore the loss of one of its most distinguished members; a scientist whose brilliant attainments and valuable contributions to metallurgy had won for him wide and ungrudging recognition. Although it was to the late Dr. Sorby that the introduction of metallographic methods for the examination of the structure of metals was, in the first place, due, it is to Mr. Osmond that the widespread application of these methods of investigation belongs.

He was born in Paris in 1849 and, during his graduate course at the École Centrale des Arts et Manufactures, he was a pupil of Professor Jordan, from whom he derived his subsequent devotion to metallurgical studies. On leaving the École Centrale, he entered the machine shops of the Fives Lille Company, and subsequently he was employed by the Compagnie Denain et Anzin at a period when the works were undergoing reconstruction and enlargement, by the addition of plant for the manufacture of steel, both by the Bessemer and the open-hearth processes. Mr. Osmond was thus enabled to acquire an intimate acquaintance with the details of the manufacture of iron and steel, and, on leaving these works, he went in 1880 to Le Creusot, where he became a member of the metallurgical staff.

Early in 1886, Professor H. Le Chatelier had perfected the thermoelectric pyrometer associated with his name, and had thus contributed a most valuable instrument of research. In that year, Mr. Osmond,

availing himself of the accurate means for measuring temperature thus furnished, embarked on an investigation of the deviations which had been observed in the temperature curves of iron and steel on heating and cooling. That these evolutions and absorptions of heat were the manifestations of a molecular change had been foreshadowed as far back as 1868 by Tschernoff, while in the following year the phenomena were described before the Royal Society by G. Gore, and later by Barrett, who was the first to explain their cause, and by Tate, Moissan, Brinell, and other observers. It was, however, reserved for Mr. Osmond to throw further light on the nature of the phenomena, and the accurate study of what have since been known as the critical points of iron and steel may be said to date from the time that he published his first paper on "The Phenomena which occur during the Heating and Cooling of Cast Steel."¹ This was followed up by a paper published in 1887 on "The Transformations of Iron and Carbon."² In 1890 he became a member of the Iron and Steel Institute, and at the May meeting in London that year he contributed his first paper to the Proceedings, entitled "On the Critical Points of Iron and Steel."

It was, however, in connection with the application of the microscope to the examination of the structure of iron and steel and to the perfection of methods of preparing, polishing, and etching the sections, that Mr. Osmond's minute and painstaking investigations were chiefly directed. To Dr. Sorby must be given the credit for first employing the microscope for this purpose, while Professor Martens was the first to develop microscopical examination along the lines suggested. To Mr. Osmond, however, belong the credit of having further elaborated the methods of investigation and of having deduced from his observations a theory capable of adequately explaining the changes of structure observed during heat treatment. He was the founder of the allotropic theory of the transformations of iron, and, in view of the controversies to which that theory has from time to time given rise, it is of interest to note that, in a letter written as recently as April 18 in the present year, he states that his opinions in regard to this theory remained unaltered.

In the course of his researches on the microstructure of steel, he discovered several new constituents: Martensite, of the existence of which he was firmly convinced, and Austenite; he also recognised and named the two transition products, Sorbite and Troostite.³

Mr. Osmond's work received widespread recognition, and he was the recipient of many honours. He was awarded monetary prizes by the Société d'Encouragement pour l'Industrie Nationale in 1888 and in 1895. In 1897 he was awarded the Lavoisier Medal, and in 1898 he was elected an Honorary Member of the American Institute of

¹ *Comptes Rendus*, vol. ciii. pp. 743, 1135.

² "Transformations du fer et du carbone dans les fers, les aciers, et les fontes blanches," *Mémoires de l'Artillerie de la Marine*, vol. xv. p. 573.

³ The term Sorbite was, however, first used by Howe (*Metallurgy of Steel*, p. 164) to distinguish certain ruby-red crystals isolated by Dr. Sorby from cast iron.

Mining Engineers. In 1906 he received the Bessemer Gold Medal of the Iron and Steel Institute, although unfortunately his health was then failing, and he was not able to attend in person on the occasion, the medal being handed, on his behalf, to the Count de Lastours, representing the French Ambassador, by whom it was transmitted to its recipient. At the Summer Meeting of the Institute in that year, he contributed, in collaboration with Mr. G. Cartaud, the third and last paper which he wrote for the Proceedings of the Iron and Steel Institute, on the "Crystallography of Iron," and he continued until quite recently to take part, from time to time, in the correspondence on papers dealing with the iron carbon theory, and to evince his continued interest in the work of the Institute.

He was interred privately on Monday, June 24, at the Cemetery of Taverny, Seine-et-Oise.

JOHN PATTINSON died on March 28, 1912, at the age of eighty-four. He was born in 1828 at Alston in Cumberland and educated at the Grammar School there. He received his early training at the Felling Chemical Works, Newcastle, where the Pattinson process of desilverising lead was carried on. After some years he entered the laboratory of Messrs. Bell Bros., Middlesbrough. In 1858 he returned to Newcastle, where he became an analytical and consulting chemist. He was appointed Food Analyst for Newcastle, and, under the Food and Drugs Act of 1875, became Public Analyst for the county of Northumberland and several other local authorities. He was Vice-President and an original Fellow of the Chemical Society, and Vice-President of the Society of Public Analysts. He was one of the founders in 1868 of the Newcastle Chemical Society, which, chiefly at his instigation, was merged in 1882 in the Society of Chemical Industry, of which he was an original member. He was also an original member of the Iron and Steel Institute, and contributed several important papers to the transactions.

THOMAS PURVIS REAY died suddenly on February 22, 1912, at his residence, Weetwood Lodge, Far Headingley, Yorks. He was born in October 1844, and served during six years, from 1859 to 1865, as a pupil in the works of Messrs. Kitson & Co., Limited, Airedale Foundry, Leeds. During the nine following years, from 1866 to 1875, he served with that firm in the designing of locomotive, tramway, and water-works engines; machinery for the manufacture of iron and steel, in connection with blast-furnaces and forges; winding and hauling-engines for collieries; hydraulic machinery for cranes, and so forth. For eight years, from 1876 to 1884, he acted as works manager, and supervised the construction of the same class of machinery. Ten years later, in 1885, he became a partner. When, in 1900, the concern was turned into a limited liability company, Mr. Reay became the managing director, and on the death of the late Lord Airedale he succeeded him as chairman of the company.

He was a member of the Institution of Civil Engineers, and a member of Council of the Institution of Mechanical Engineers. He was elected a member of the Iron and Steel Institute in 1882.

The Chevalier CECIL DE SCHWARZ died on January 12, 1912. He was born near Vienna and belonged to an old Austrian family. He studied at the Polytechnical College, Vienna, and at the Imperial Academy for Mining Engineers at Leoben in Styria. He was then appointed engineer at some iron and steel works in Austria belonging to his family and founded by his great-grandfather at the end of the eighteenth century. Later on he became manager of a German iron-works. In 1881 he was engaged by the Government of India to report on the financial prospects of iron working on modern principles in that country. His reports on the subject were published in the *Official Gazette of India* on August 5, 1882. He then erected blast-furnaces and foundries in India, trained the natives for the work, and managed the works for the Government for a period of about eight years, after which they became the property of a private company. He then returned to Europe, where he commenced practice at Liège as a consulting engineer. He was a constant contributor to the proceedings of the Institute, to which he presented the following papers: "On the Utilisation of Blast-furnace Slag"¹; "On Portland Cement Manufacture from Blast-furnace Slag"²; "On the Use of Oxygen in removing Blast-furnace Obstructions"³; and "On the Briquetting of Iron Ores."⁴ He was elected a member of the Iron and Steel Institute in 1890.

HERBERT ARTHUR SWAN died on December 13, 1911. He was head of the firm of Messrs. Swan Brothers of Middlesbrough. He was elected a member of the Iron and Steel Institute in 1873. During the visit of the Institute to Middlesbrough in 1908 he served on the Local Reception Committee.

ROBERT SYKES of Stalybridge died in February 1912, at the age of eighty-three. He was born at Milnsbridge, in Yorkshire, which place he left for Stockport over fifty years ago, commencing business there as an ironmonger with his brother, Mr. Ellis Sykes. Subsequently he went to Stalybridge, where he commenced business on his own account under the name of R. Sykes & Sons, Limited. He was elected a member of the Iron and Steel Institute in 1881.

JOHN TURTON died on January 25, 1912, at his residence, Hill Turrets, Parkhead, Sheffield. He was born in 1843, and commenced his business career early in life with Messrs. John Charles & Sons, at that time the proprietors of The Kelham Rolling Mills, Sheffield. In 1868 he acquired the Vulcan Rolling Mills, which he rapidly developed

¹ *Journal of the Iron and Steel Institute*, 1900, No. I., and 1908, No. I.

² *Ibid.*, 1903, No. I.

Ibid., 1906, No. I.

⁴ *Ibid.*, 1910, No. II.

and extended, at a later date taking his three sons into partnership. He was well known in Sheffield and other business circles, but took no prominent part in local public matters. He was elected a member of the Iron and Steel Institute in 1883.

JAMES WHITE died suddenly on January 29, 1912. He was managing director of Thos. Allan & Sons, Limited, Bon Lea Foundry, Thornaby-on-Tees. He was about sixty years of age, and took over the management of the Bon Lea Foundry fifteen years ago. He formerly carried on an extensive business as a pipe manufacturer in Glasgow. He was elected a member of the Iron and Steel Institute in 1908, when he served as a member of the Local Reception Committee during the visit of the Institute to Middlesbrough.

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INSTITUTIONS.

The Publications of the Institute are exchanged for those of the following Institutions :—

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| Board of Trade. | Institution of Naval Architects. |
| Chemical Society. | National Physical Laboratory. |
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| Geological Society. | Royal Institute of British Architects. |
| Geological Survey. | Royal Institution. |
| Home Office. | Royal Microscopical Society. |
| Imperial Institute. | Royal Society. |
| Institute of Chemistry. | Royal Society of Arts. |
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| Institution of Civil Engineers. | Society of Chemical Industry. |
| Institution of Electrical Engineers. | Society of Engineers. |
| Institution of Mechanical Engineers. | Society of Public Analysts. |
| Institution of Mining and Metallurgy. | University College. |
| Institution of Mining Engineers. | |

PROVINCIAL.

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| Armstrong College, Newcastle-on-Tyne. | North-East Coast Institution of Engineers and Shipbuilders. |
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| Institution of Engineers and Shipbuilders in Scotland. | South Staffordshire Ironmasters' Association. |
| Leeds University, Engineering Society. | South Wales Institute of Engineers. |
| Liverpool Engineering Society. | Staffordshire Iron and Steel Institute. |
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| Manchester Geological and Mining Society. | West of Scotland Iron and Steel Institute. |
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COLONIAL AND FOREIGN.

Colonial.

Australasian Association for the Advancement of Science.
 Australasian Institute of Mining Engineers.
 Canada, Department of Mines.
 Canadian Institute.
 Canadian Mining Institute.
 Canadian Society of Civil Engineers.
 Geological Survey of India.
 Mining Society of Nova Scotia.
 Mysore Geological Department.
 New South Wales, Department of Mines.
 Queensland University.
 Royal Society of New South Wales.
 Victoria, Department of Mines.
 Western Australia, Department of Mines.

United States.

American Association for the Advancement of Science.
 American Foundrymen's Association.
 American Institute of Mining Engineers.
 American Iron and Steel Association.
 American Society of Civil Engineers.
 American Society of Mechanical Engineers.
 Engineers' Society of Western Pennsylvania.
 Franklin Institute.
 Illinois University.
 Massachusetts Institute of Technology.
 New York Academy of Sciences.
 Ordnance Office, War Department, Washington.
 School of Mines, Columbia University, New York.
 Smithsonian Institution.
 United States Geological Survey.
 Washington Academy of Sciences.
 Washington, Department of Commerce and Labour.

Austria.

K. K. geologische Reichsanstalt.
 Oesterr. Ingenieur- und Architekten-Verein.

Belgium.

Association des Ingénieurs sortis de l'École des Mines de Liège.
 Ministère de l'Intérieur.
 Union des Charbonnages de Liège.

France.

Comité des Forges.
 Société d'Encouragement pour l'Industrie Nationale.
 Société de l'Industrie Minière.
 Société des Anciens Elèves des Écoles Nationales d'Arts et Métiers.
 Société des Ingénieurs Civils.
 Société Scientifique Industrielle de Marseille.

Denmark.

Teknisk Bibliotek.

Germany.

Deutsches Museum.
 Königliche Bergakademie in Freiberg.
 Königliches Materialprüfungsamt.
 Verein deutscher Eisen-und-Stahl Industrieller.
 Verein deutscher Eisenhüttenleute.
 (Journal "Stahl und Eisen").
 Verein deutscher Ingenieure.

Italy.

Associazione fra gli Industriali Metallurgici Italiani.
 Collegio Nazionale degli Ingegneri Ferroviari Italiani.
 Reale Accademia dei Lincei.

Peru.

"Cuerpo de Ingenieros de Minas."

Sweden.

Geological Institution of the University of Upsala.
 Jernkontoret.

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UNITED KINGDOM.

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| <p>"African Engineering."
 "American Machinist."
 "Automobile Engineer."
 "Biggs and Sons' Contractors' Record."
 "Cassier's Magazine."
 "Coal and Iron."
 "Colliery Guardian."
 "Concrete and Constructional Engineering."
 "Contract Journal."
 "Contractor's Chronicle."
 "Electrical Engineering."
 "Electrical Review."
 "Electrical Times."
 "Electrician."
 "Engineer."
 "Engineer and Iron Trades Advertiser."
 "Engineering."
 "Engineering Review."
 "Hardware Trade Journal."
 "Illuminating Engineer."
 "Iron and Coal Trades Review."</p> | <p>"Iron and Steel Trades Journal."
 "Iron Trade Circular."
 "Ironmonger."
 "Ironmongers' Chronicle."
 "Machinery Market."
 "Marine Engineer."
 "Mechanical Engineer."
 "Page's Weekly."
 "Petroleum Review."
 "Phillips' Monthly Register."
 "Practical Engineer."
 "Railway News."
 "Railway Times."
 "Science Abstracts."
 "Science and Art of Mining."
 "Shipping World."
 "South African Engineering."
 "Statist."
 "Steamship."
 "Syren and Shipping."
 "Technical Index."
 "Tramway and Railway World."</p> |
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COLONIAL AND FOREIGN.

Colonial.

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 "Indian Engineering."
 "Indian Textile Journal."

United States.

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 "Bradstreets."
 "Castings."
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 "Engineering Magazine."
 "Engineering News."
 "Industrial World."
 "Iron Age."
 "Iron Trade Review."
 "Machinery."
 "Metallurgical and Chemical Engineering."
 "Mines and Minerals."
 "Mining and Engineering World."
 "Power."

Austria.

- "Oesterr. Zeitschrift für Berg- und Hüttenwesen."

Belgium.

- "Moniteur des Intérêts Matériels."
 "Revue Universelle des Mines."

France.

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 "Echo des Mines."
 "Fonderie Moderne."
 "Génie Civil."
 "Mois Scientifique et Industriel."
 "Portefeuille Economique."

Germany.

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 "Eisen-Zeitung."
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 "Zeitschrift für Werkzeugmaschinen und Werkzeuge."
 "Zeitschrift für Elektrochemie."
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COLONIAL AND FOREIGN—continued.**Italy.**

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Spain.

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UNITED KINGDOM.

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 "Mining Journal."
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 "Reports of the British Fire Prevention Committee."

COLONIAL AND FOREIGN.**Colonial.**

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Roumania.

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SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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In the preparation of these Notes the Editor has been assisted by L. P. SIDNEY,
Assistant Secretary, J. NEWTON FRIEND, D.Sc., and others.

IRON ORES.

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I.—OCCURRENCE AND COMPOSITION.

Origin of Ore Deposits.—E. K. Soper¹ discusses the origin of ore deposits, and points out that the earliest contribution to the study of the subject was made in 1791 by Werner, the German geologist. Ore deposits, whatever their origin, may be divided into two great classes: those formed contemporaneously with the rocks in which they occur, or syngenetic, and those formed subsequently to the rocks in which they are found, or epigenetic. Except for certain ores in igneous and sedimentary rocks, most ore bodies are regarded as falling into the second division. Water is a most important ore carrier, but different opinions exist regarding the source of water. Certain types of ore deposits are clearly the result of contact or regional metamorphism, while others are due to solfataric action. Most of the larger and richer deposits, whatever their origin, are only made workable by some process of secondary enrichment. Thus, most ore deposits are the result of two or more concentrations from an original disseminated condition in the rocks. Lastly, there are certain superficial deposits (including placers and stream deposits) which are derived from the disintegration of veins *in situ*.

G. W. Miller² discusses the origin of metalliferous ores.

Distribution of Iron Ore.—A. Selwyn-Brown³ discusses the physical and chemical characteristics of the principal kinds of iron ores, their distribution in various parts of the world, and their relative abundance. The possibilities are particularly considered of the utilisation of minerals not at present being worked on a

¹ *Engineering and Mining Journal*, vol. xcn. pp. 897-900, 947-949.

² *Mining and Engineering World*, vol. xxxvi. pp. 515-516.

³ *Engineering Magazine*, vol. xlii. pp. 41-46, 213-232.

commercial scale. In conclusion, a summary is given of the iron ore resources of all the chief iron-producing countries of the world.

Iron Ore in Great Britain.—Flegel¹ gives an account of the geological conditions, the occurrence, and composition of iron ores in Great Britain. Tables are given showing the quantity of ore mined in the country in each year since 1873, and the imports of ore at the present time, with the countries whence imported.

Iron Ore in France.—L. Davy² describes the iron ores of Anjou and of south-eastern Brittany. The area described is that situated between the Loire and the Vilaine. Iron-bearing minerals are found throughout this region in varying forms; in the eruptive rocks, the outcrops of which have been investigated in the metamorphic rocks of Peru, in the veins found in Haute Loudéac, and in various sedimentary deposits. The minerals appear to have been used in Gallo-Roman times and, to a certain extent, during the Middle Ages, and as lately as 1831, Fournel placed on record the fact that in Normandy, Brittany, and Anjou alone there were forty-eight blast-furnaces in operation. Mining was generally carried on by open-cast methods, although a few exceptions, such as the shafts at Ferrière-aux-Étangs, occur. The iron industry of this district has slowly diminished, and in 1880 the last blast-furnace, which was situated at Tobago, near Redon, was dismantled. The following year, however, mining operations were recommenced and carried on until 1892, when the competition with Spanish ore led to the operations being suspended. Of late, production has once again been undertaken, but the exhaustion of the surface deposits has led to a general recognition of the necessity of sinking shafts if the region is still to be regarded as a factor in the iron ore production of France.

It is stated³ that the old researches made in the centre of France at Anzat-le-Lugnet, in the Puy-de-Dôme district have shown the existence there of hæmatite iron ore. Comparatively recently other researches have been carried out by the Commentry-Fourchambault Company, who were, however, compelled to abandon them, particularly in view of transport difficulties. More recent researches at that place have revealed the existence of a hæmatite iron ore bed, having an area of 100 square feet and a length of several miles.

Iron Ore in Germany.—K. Masling⁴ gives a general account of the geology of the ore deposits of the principality of Waldeck. Hæmatite occurs on the Martenberg and in the Kellerwald, oolitic iron ore is found in the Lias near Wethen, and manganiferous ore in the Permian limestone. Some account of the history of mining in the principality is also given.

¹ *Gluckauf*, vol. xlvii. pp. 1801-1803.

² *Revue de Métallurgie, Extraits*, vol. viii. pp. 779-780.

³ *Engineering*, vol. xcii. p. 287.

⁴ *Zeitschrift für praktische Geologie*, vol. xix. pp. 361-377.

Iron Ore in Norway.—It is reported¹ that some iron ore deposits of considerable magnitude have been discovered in the county of Bamle, in the south of Norway. The lode has been traced for a distance of about three miles, with an average thickness of 28 feet, being covered in some places by an apparently thin layer of gneiss. The deposits consist of specular iron ore of good quality. The conditions for working these deposits are exceptionally good, as they are situated close to the port of Brevikstrand.

A. Udhaug² describes the iron ore mines at Sydvaranger, Norway.

Iron Ore in China.—T. T. Read³ discusses the iron ore resources of China. Iron ore is the second mineral of importance, the coal resources being the more important, and it is pointed out that the security of the future of China as a mineral-producing nation may easily be appreciated since it is founded upon an abundant supply of both coal and iron, the two bases of industrial development. In some districts the simultaneous occurrence of coal and iron ore have led to the development of a native smelting industry, but while these deposits suffice for such methods, they are not suited to modern processes, and iron ores of still higher quality exist which have not yet been developed because the necessary supply of coal does not exist near by. One of the principal iron ore regions is the P'ing-t'ing-chou district in Shansi. The iron ores are limonite and hæmatite, occurring in shales and sandstones of Carboniferous age. Usually they are in masses of no great size or in beds or flat veins. It follows, therefore, that no sufficient supply of uniform quality can be obtained from these deposits to form the basis of blast-furnace work on a large scale. Suitable deposits are reported to be found in the Honan province, and analyses of this ore from Tai Yang show the following composition:—

	I.	II.
	Per Cent.	Per Cent.
Iron	53.88	45.50
Silica	4.67	11.15
Alumina	3.46	6.42
Manganese dioxide	0.57	0.51
Lime	2.21	5.50
Magnesia	trace	0.25
Phosphoric anhydride	0.57	1.08
Sulphur	0.074	0.016
Carbonic acid	9.37	2.70
Water	2.20	75.0

In making iron by the native methods, the ore, mined through shallow, round, or rectangular shafts, is broken into small pieces and hand-sorted. At the smelting plant it is mixed with 50 per cent. of its

¹ *Iron and Coal Trades Review*, vol. lxxxiv. p. 643.

² *Ibid.*, pp. 161-163.

³ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 315-343.

volume of coal and packed into cylindrical crucibles, 5 inches in inner diameter and usually 45 inches high. From 250 to 275 of these crucibles are set upright in a rectangular furnace, about 12 feet by 6 feet by 4 feet. Air space is secured at the bottom by a layer of broken crucibles, over which is placed a layer of coal. The crucibles are set in place, with coal between them. The front side is closed, and the whole covered over with coal and allowed to burn by natural draught for three days. The crucibles are then removed and the contents taken out. This operation usually involves breaking the bottom part of the crucible, which now contains an irregular bloom of iron of very variable composition. The bloom is sold to makers of wrought iron, the accompanying small pieces of iron are sold to makers of cast iron, and the coke is used in the manufacture of crucibles. The product is not pig iron in the ordinary sense of the word, as it contains very little carbon and is malleable. The bloom is worked into wrought iron by heating in a wood fire and hammering down into a rectangular ingot, and the small pieces of iron are mixed with coal, placed in crucibles and blown by hand in a smaller furnace, the contents of several crucibles being subsequently poured into one, from which the final product is poured into moulds. From this product utensils of extraordinary thinness can be cast, as the iron contains as much as 5 to 7 per cent. of phosphorus, which has been taken up from the coal during the reduction and remelting. It is not improbable that the high phosphorus content of the Shansi coals has been the chief factor in the great development of this industry, as it has afforded an easy means of securing the high phosphorus iron necessary in making thin castings. The only modern steelworks in China are those at Hanyang, where both blast-furnace and steel plant are located. The iron ores are obtained from Ta-Yeh, and are a good quality of hæmatite. An analysis is given below:—

	Per Cent.
Iron	60 to 62
Phosphorus	0·05 to 0·25
Sulphur	0·05 to 0·12
Silica	3 to 5
Alumina	1 to 2
Manganese	0·2 to 0·4
Copper	0·05 to 0·25

A description is given of the chief localities in which iron ore has so far been discovered in China, including Mukden, Shansi, Chili, Shantung, Kiang-su, An-hwei, Upper Ho-nan, and Ssu-ch'uan. Although the knowledge of the iron ore resources of the Chinese Empire is still inadequate, it would appear, generally speaking, that ores are widely distributed throughout the Empire. A bibliography is appended.

Iron Ore in the Philippines.—W. D. Smith¹ and P. R. Fanning, in reporting on the mineral resources of the Philippine Islands, state that promising deposits of hæmatite have been found near Mambulao,

¹ Bureau of Science, Manila; *Iron and Coal Trades Review*, vol. lxxxiv p. 49.

and on Calumbayanga Island, where the exposures are particularly conspicuous. This island is situated some four miles west of the town of Mambulao, in Luzon, the largest of the Philippine Islands. It lies at a point about 124 miles nearly due east of Manila, and may be reached overland in two or three days, or in three days by coastwise boat. The immediate area is of moderate relief, and the hills to a great extent represent base levelling. Soil of a possible thickness of 10 feet occurs generally over the area, except on the hæmatite, where, owing to the resistant nature, the soil is somewhat thinner, and is made up of softer hæmatite or limonite, mixed with innumerable boulders of the harder hæmatite. The ore can be traced for a distance of about two miles, and on the surface, where revealed by true outcrops, the width varies up to 50 feet. Owing to the scarcity of true outcrops, it cannot at present be said that this is the average width, and in view of the mode of formation, the probability is that the outline of the deposit is quite irregular.

The quality of the hæmatite is shown by the following analyses of three samples:—

	1.	2.	3.
	Per Cent.	Per Cent.	Per Cent.
Iron	57.11	63.69	46.06
Phosphorus	0.001	0.005	0.008
Sulphur	0.138	0.070	0.067

Other analyses have shown an iron content averaging 60 per cent. The hæmatite is very compact and hard, and in appearance is very similar to the hard Lake Superior ore, such as that from the Vermilion Range, Minnesota. Some specular hæmatite in flat crystals is occasionally seen, and a small amount of magnetite is not infrequent.

Iron Ore in Algeria.—Dussert¹ deals exhaustively with the iron ore deposits of Algeria. The discovery of many of the deposits dates back to 1830; but although many concessions had previously been granted, actual working was not begun before 1865. The geology of the deposits is described in detail. Generally speaking, where the ore occurs in veins, and where it occurs in pockets, as the result of metasomatic transformation of calcareous rings, its formation is prior to the oligocene, but later than the mid-eocene periods. Magnetite is one of the most important minerals met with in the Algerian subsoil, and forms almost entirely the oxidised portion of the deposits at Ain Sedma, while mixed with hæmatite it forms in the Bône district stratified masses of reddish mineral, which are both rich and pure. Below the surface the sesquioxide disappears, and the mineral becomes greyish, and may be regarded as a magnetite with calcareous gangue. In other regions the sands derived from the disintegration of the

¹ *Annales des Mines*, Series XI. vol. 1. pp. 69-133, 135-256.

eruptive rocks of the region are rich in titaniferous magnetite, and contain traces of tungsten. A little magnetic iron has been found in the Benisaf region, its formation being due to the action of labradorite on hæmatite. Generally speaking, the bulk of the exported Algerian ores are either hæmatite or limonite, and in the production for 1910, which amounted to 1,101,109 tons, only 85,349 tons of magnetic ores and 3·518 tons of calcined siderose were included. Manganese is found in almost all the ores, but its proportion varies, and it is seldom sufficiently high to influence their value. The ores highest in manganese are those from Rar el Maden and Sebabna, the percentages being 5·55 and 8·5 to 9 per cent. respectively. Pockets of ore have, however, been met with containing as much as 30 per cent. of manganese, and numerous outcrops of pyrolusite have been found in the department of Constantine. There is, however, no actual production of manganese ore in Algeria. The geology and topography of each of the principal regions are then considered separately and at length, analyses being given of the typical ores produced in each locality. In Oran the principal localities in which iron ore is found are Msirda, Beni Ouarsous, Benisaf, Oran Proper, and Arzew. The Benisaf ores are the most important. The following analyses show respectively the richest ore and the poorest ore contained in this region:

Analysis of Ores of Benisaf.

	Ore from Sidi Brahoni.	Ore from Sidi Sah.
	Per Cent.	Per Cent.
Iron	64·820	50·950
Manganese	1·080	2·670
Alumina	0·640	1·000
Lime	0·200	5·150
Magnesia	traces	0·793
Silica	3·600	6·200
Sulphur	0·010	0·203
Phosphorus	0·053	0·067
Pyrites	nil	0·769
Copper	nil	traces

The other ores are of a character intermediate between these two extremes. In the department of Algiers the chief ore regions are the sea coast between Ténès and Cherchell: Cheliff, Zaccars, Mitidjien Atlas district; and Krashna. The ores of the department of Algiers are, generally speaking, lower in iron than those of Benisaf. In the department of Constantine iron ores occur in Kabalie des Barbors, at Collo, Filfila, and Edough, in the Bibans, and at Djebel Ouenza and the Djebel Bou Kadra. The ores are mostly a mixture of hæmatite and limonite, and their percentage of iron is fairly regular. The mineral occurring at Bou Kadra is hæmatite, samples of which have been found to contain as much as 63 to 70 per cent. of iron. Some of the deposits are, however, high in sulphur.

Iron Ore in South Africa.—In the first interim report on the mining industry of South Africa¹ which has been issued since the inauguration of the Union, it is stated that claims have been pegged on huge masses of iron ore associated with norite in the Tugela Valley, a few miles from Middle Drift. Their position, far removed from railways and in rough country, is against their development, but the immense size of the deposits and the character of the ore as indicated by a few analyses which are available, make it desirable that the deposits should be properly examined and their character placed on record. The following are analyses of surface samples from the deposit:—

	No. 1.	No. 2.
	Per Cent.	Per Cent.
Ferrous oxide	9.21	23.18
Ferric oxide	64.33	46.89
Titanic oxide	9.60	7.52

The question of an iron industry in Natal presents very much the same features as exist in the Transvaal. Numerous deposits are scattered over the country, many of which on cursory examination give erroneous impressions of large masses of mineral, but some of which, no doubt, contain large quantities of iron ore of medium quality. There is no present prospect of producing large quantities of iron and steel at a profit, but from time to time small quantities of the better-class ores will be worked where exceptional facilities permit, and some of the numerous oxides will continue to be employed in the paint and other local industries.

Iron Ore in Canada.—H. Fréchette² describes the western portion of the Torbrook iron ore deposits in Annapolis County, Nova Scotia. These deposits are situated on the south-eastern side of the Annapolis Valley. The ore-bearing district extends south-westward from the line between King's and Annapolis counties, for a distance of about five miles, and is slightly over a mile in width. There are two parallel zones of ore, distant about one mile from one another, one of which is on the north side, the other on the south side of the area, which is locally known as "South Mountain." Both on South Mountain and on the north side, numerous pits have been dug thus exposing the ore, which is in beds conformable with the slates and quartzites in which they occur. The northernmost bed, known as the "Leckie bed," is of a hard hæmatite which is slightly magnetic. About 100 feet south-east of this is a bed of fossiliferous magnetite, known as the "Shell" bed. On South Mountain only one bed is seen. The ore in most parts of this bed is a low-grade magnetite, highly siliceous, and of a waxy lustre. Very few fossils are to be seen in it.

¹ *Iron and Coal Trades Review*, vol. lxxxiii, p. 1018.

² Canada, Department of Mines, Mines Branch Report No. 110.

The following analyses show the character of the ore on South Mountain :—

	Per Cent	Per Cent.	Per Cent.	Per Cent.
Iron	47.09	49.51	54.53	45.62
Alumina	3.70	5.46	2.50	4.93
Lime	4.55	2.15	0.95	4.15
Magnesia	0.45	0.90	0.43	0.42
Phosphorus	1.39	0.745	1.00	1.44
Sulphur	0.051	0.009	0.003	0.01
Silica	20.20	19.56	12.68	22.16

In most cases the ore is low in iron, and highly siliceous. The bed is made up of alternate narrow bands of ore and slate. The widest of these ore bands seldom attains a thickness of more than 5 feet. The aggregate thickness of ore averages about 8 feet 4 inches in a total thickness of 18 feet 10 inches. Owing to the low-grade character of the ore and the difficulties of transportation, the South Mountain bed can hardly be looked upon as showing much commercial possibility. The "Shell" bed, on the north side, is magnetite containing numerous fossils of Lower Oriskany or Eo-Devonian age. The following is an average analysis of the ore from various parts of this bed :—

	Per Cent.
Iron	44.132
Silica	16.605
Alumina	4.843
Lime	6.790
Phosphorus	0.750
Sulphur	0.098

Iron Ore in the United States.—A. H. Brooks¹ notes the occurrence of iron ore in Alaska. In the absence of any development of the coking coals and the lack of transportation, there has been little encouragement to prospect the deposits of Alaska. The best known of the deposits of magnetite are those of Prince of Wales Island. Iron ore deposits of the segregated type occur near Haines, in south-eastern Alaska, but their commercial value remains to be established. They consist of primary magnetite disseminated in a basic rock composed of pyroxene and hornblende. The best specimens examined contained a maximum of 30 per cent. of magnetite.

J. Sanders² describes the occurrence of hæmatite in veins in the Globe district of Arizona, and discusses the mode of its formation from pyrites. The oldest and most typical formation is that which occurs at the Old Dominion Mine, where the most prominent feature is the great depth of the zone of oxidation, extending to many hundred feet, sulphide ores not being encountered except in the deepest workings. On the other hand, in veins of the Summit class lying in the hard

¹ *United States Geological Survey, Bulletin No. 480*, pp. 90-91.

² *Engineering and Mining Journal*, vol. xcii. pp. 1191-1192.

schist, sulphide ores are encountered almost from the surface down, although some oxidation may extend to a depth of 200 feet. The action of alkaline or metallic carbonates upon sulphide minerals, such as pyrite, may account for the occurrence of hematite in association with pyrite and chalcoppyrite in the mine.

Important new finds of iron ore have been made on the Mesaba and other ranges.¹ The Newport Mining Company has been successful in its exploratory work several miles east of the Newport mine at Ironwood, Gogebic Range, and has discovered an immense deposit of high-grade ore that bids fair to equal in proportions the Newport deposit itself. A strike of much significance and apparently of considerable value has also been made at the Silverman property east of Ely, Vermilion Range. Two diamond drills are in commission, and each of these has encountered a body of high-grade ore that appears of large proportions. The deposit is only a little more than 100 feet beneath the surface. The M. A. Hanna interests of Cleveland have added an important deposit of iron ore to their Marquette Range holdings. The property concerned consists of 200 acres adjoining the American Mine on the west. It has been explored extensively, and is known to possess great mineral value. In addition to the lease there has been executed between the same interests an option covering 160 acres still farther west in the same section. It is believed that this latter tract contains a large ore body also. Sufficient work has already been done to disclose the presence of Bessemer ore, but its extent can be determined only by systematic exploration.

G. C. Stoltz² describes the Cheever Mines, Port Henry, New York. The deposits, which consist of magnetite, are among the oldest of the iron mines in New York State, and were worked as far back as 1785. The deposits can be traced along the strike for nearly a mile, and the most southern of the ore bodies outcrops for about a quarter of a mile from the shores of Lake Champlain. The ore bodies occur in acid gneiss, or sometimes syenitic gneiss. Most of the magnetite is granular and basic, containing variable quantities of green to pink apatite with green pyroxene constituents. The ores are probably of sedimentary origin. The methods of mining and concentrating are described.

It is stated³ that one of the oldest iron ore mines in the United States is that known as the Forest of Dean, situated about five miles west of Fort Montgomery on the Hudson River, Orange County, New York State, which has been worked since 1756.

The ore deposit is a large prism-shaped mass 120 feet high by 90 feet wide, its form being due probably to its having folded upon itself. It dips north-west at an angle of about 23 degrees, and has been worked along this slope for a distance of about half a mile. The working slope is on the footwall, which is gneiss. The ore as shipped averages more than 60 per cent. of iron. According to analysis taken in the days of hand cobbing, the ore averaged as follows:—

¹ *Iron Age*, vol. lxxxviii. p. 702.

² *Engineering and Mining Journal*, vol. xcii. pp. 809-812.

³ *Mines and Minerals*, vol. xxxii. pp. 184-185.

	Per Cent.
Silica	5.00
Alumina	trace
Lime	5.51
Magnesia	1.19
Iron oxide	83.56=metallic iron, 60.5
Phosphoric acid	2.30
Carbon dioxide	1.05
Water	0.20

A discovery of iron ore is reported¹ from Ayr, Pennsylvania, the estimates of its quantity ranging from 500 to 1000 million tons, much of which is said to be of Bessemer quality. It is believed that the property contains at least one billion tons of high-grade ore, consisting of black hæmatite, brown hæmatite, red hæmatite, and carbonate of iron. On the other hand, from a report of the State Geologist, it appears that while there is an abundance of ore there, principally brown hæmatite, the estimated deposit of commercial ore, in his opinion, is far short of one billion tons. In regard to quality, selected samples, he declares, may contain 60 per cent. of iron, but it is doubtful whether any of the ore bodies will average 50 per cent.

Iron Ore in Brazil.—C. K. Leith² and E. C. Harder describe the hæmatite ores of Brazil, and compare them with the hæmatites of Lake Superior. The important ores in the Minas Geraes district of Brazil are massive hæmatite and jacutinga. Secondary concentration resulting from the leaching of impurities has enriched much of the jacutinga ore, but has not been sufficient to form ore deposits from ordinary iron formation or itabirite, as has been the case in the Lake Superior district. Brazilian ores are associated with vast quantities of residual or transported fragmental ores, usually of a somewhat lower grade than the bedded ores, and though not able to be immediately utilised, they nevertheless constitute enormous fair-grade deposits for the future. Estimates of tonnage for the region as a whole would be premature with the present state of knowledge, but it is certain that the estimate of Derby, of two millions for the district, is conservative. Of the high-grade massive hæmatite and jacutinga, ranging from 63 per cent. to 69 per cent. in iron, the tonnage is probably not far short of the total reserve of available ores in the Lake Superior region. The grades of the hæmatites vary, of course, with the content of silica and phosphorus, but the conspicuous thick lenses of massive iron ore are probably the richest ores of Bessemer hæmatite in the world. Some jacutinga ores are equally rich, but others are somewhat high in phosphorus and silica. The iron ores of the Minas Geraes district are more like the Lake Superior ores in type, geological associations, richness, and quantity than anything yet discovered.

Iron Ore in Cuba.—The nature of the iron ore deposits of Mayari, which have already been the subject of litigation in the

¹ *Iron and Coal Trades Review*, vol. lxxxiv, p. 605

² *Economic Geology; Iron and Coal Trades Review*, vol. lxxxiv, pp. 170-172.

United States, is reported upon at length by R. A. de Yarza,¹ R. S. Lozano, and V. Kindelan, who describe the deposits and submit a number of definitions from various sources relating respectively to iron ore and ochre. They also give a summary of the laws bearing on the subject, and tables of analyses prepared by Pattinson and Stead. The ultimate opinion they arrive at is adverse to regarding the ores as ochre.

J. I. del Corral² also deals with the legal considerations involved.

D. E. Woodbridge³ describes the iron ore deposits of Cuba. On the north coast there are iron ore deposits in the nature of laterites amounting to about 200,000,000 tons. They lie in the province of Oriente, near the east end of the island and adjacent to the sea. The deposits consist of a brown ore, high in moisture and alumina, very low in silica and phosphorus, containing about 0·7 per cent. of nickel. The average thickness of the beds is about 20 feet. A typical analysis of these ores, dried at 212 degrees, is as follows:—

	Per Cent.
Silica	3·37
Iron	43·67
Alumina	13·07
Chromium	1·745
Nickel }	0·8025
Cobalt }	
Phosphorus	0·008
Sulphur	0·107
Combined H ₂ O	11·59

Hygroscopic moisture varies with the seasons, but averages about 15 to 20 per cent.

Native Iron.—A. A. Inostzanzeff⁴ states that a specimen of native iron has been obtained from Russian Island, Vladivostok. The specimen, which was taken from a borehole passing through quartz-porphphy and Triassic sandstone, is brown and resembles limonite in appearance, but it has a much higher specific gravity (7·007), and is strongly magnetic. On a fresh fracture it shows a peculiar oolitic structure, with black grains set in a silver-white metallic ground-mass. The structure of the metallic portion as seen under the microscope is not like that of other native irons, but is very similar to that of artificial cast iron. The structure shows bands of ferrite, granular cementite, and a ground-mass of pearlite, whilst graphite is also present. Analyses by S. A. Jakowleff gave:—

	Per Cent.
Iron	93·87
Combined carbon	0·33
Free carbon	2·87
Aluminum	0·16
Manganese	0·66
Silicon	1·55
Sulphur	0·04
Total	99·48

¹ *Revista Minera*, vol. lxxi, pp. 495-504.

² *Ibid.*, pp. 457-458.

³ *Canadian Mining Journal*, vol. xxxii, pp. 738-741.

⁴ *Zeitschrift für Krystallographie und Mineralogie*, vol. i, pp. 61-62.

In composition also the material is thus identical with artificial cast iron. It is suggested that this "native cast iron" was formed by the action of the intruded igneous rock on coal and iron ore in the sedimentary rocks.

Chrome Ore.—An important deposit of chromite has been found at Selukwe, in Rhodesia,¹ and during 1910 no less than 44,002 tons were shipped. The output is increasing rapidly. The deposit consists of a huge segregated mass associated with serpentine and is easily quarried. It is close to the railway; the cost of mining is low, and the supply is exceedingly large. Chromite is found in several other parts of Southern Rhodesia, and its occurrence appears to be connected with the great intrusion of picrite which runs north and south through Southern Rhodesia from the Zambesi to the Limpopo.

Manganese Ore.—E. Přivoznik² discusses the industrial importance of manganese and its compounds. The occurrence of the ore and the use of manganese in the smelting and refining of iron and in the chemical and dyeing industries are considered.

Hoyer³ describes the manganese ore deposits of the southern Sierra Morena in the province of Huelva, Spain. The origin of the deposits is discussed.

Molybdenum Ore.—T. L. Walker⁴ describes the occurrence of molybdenum ores in Canada, and deals with the nature of the ores, their uses, production, and methods of concentration.

Nickel Ore.—The occurrence of nickel-bearing pyrrhotite in Floyd Co., Virginia, is reported.⁵ The ore occurs on the hillside and is associated with some chalcopyrite. The percentage of nickel is about 1.75, and there is 0.4 per cent. of cobalt present.

Tungsten Ore.—R. S. Lozano⁶ gives a description of the tungsten resources of Spain and Portugal, together with statistics as to the production of ores containing tungsten. In 1900 the production was less than 2 tons, but this output had risen in 1908 to no less than 226 tons. The production in Portugal was nearly three times as considerable, the output in 1909 having amounted to 710 tons. The tungsten deposits extend over the whole of the West Iberian Peninsula, and veins penetrating the quartz are found as widely apart as in Cordova, Andalusia, Salamanca, and Galicia. In Portugal the veins chiefly occur in the north. Generally speaking, the northern deposits

¹ *Engineering and Mining Journal*, vol. xcii. p. 955.

² *Oesterreichische Zeitschrift*, vol. lix. pp. 582-587.

³ *Zeitschrift für praktische Geologie*, vol. xix. pp. 407-432.

⁴ Canada, Department of Mines, Mines Branch, Report No. 93.

⁵ *Engineering and Mining Journal*, vol. xcii. p. 844.

⁶ Paper read before the International Congress of Mining, Metallurgy, Applied Mechanics, and Practical Geology, Dusseldorf; *Bulletin de la Société de l'Industrie Minière*, Series IV, vol. xv. pp. 268-269.

of tungsten are accompanied by tin ores, but in the south they occur alone.

It is stated¹ that the tungsten ores of Portugal are remarkable for their purity, containing neither tin, sulphur, phosphorus, nor bismuth; and, after being dressed, contain from 70 to 72 per cent. of tungstic acid. By reason of this purity these ores are largely used in the French electro-metallurgical industry for the production of ferro-tungsten.

Vanadium Ore.—F. F. V. Curran² describes the carnotite deposits of south-west Colorado. They occur in Paradox Valley. At Dry Creek, 6 miles west of Naturita and 46 miles west of the nearest railway station, Placerville, the valley is 3 miles wide and over 50 miles long, and is, generally speaking, an expanse of sandy loam, dry and dusty during the greater part of the year, but yielding abundant crops when favoured with the infrequent rains. The carnotite ore-bodies outcrop from the sloping sides of the mesa about 600 feet above the valley's level, and may be mined by horizontal tunnels driven in from the surface. The ore is roughly sorted and placed in canvas sacks, holding about 85 lbs. each, and is hauled by wagon to Placerville. The best-known mine is the Jodandy, at an elevation of about 6000 feet above sea-level. The ores are of variegated colours and richness, ranging from vivid canary yellow, with 10 to 15 per cent. of uranium oxide, to greenish black Kentsmithite. Red hydro-calcium vanadate also occurs, containing as much as 90 per cent. of vanadium oxide. The demand for carnotite as a source of vanadium employed in medicine, dyeing, and in the iron and steel and copper industries, as well as for the extraction of radium, is increasing rapidly. Fully 90 per cent. of the carnotite ore production is shipped either to Liverpool or to Cannonsburg, Pennsylvania. Carnotite is the most desirable of the ores of vanadium, for it can be cheaply and easily treated, and a 10 per cent. solution of sulphuric acid can extract 86 per cent. of the vanadium in fifteen minutes, or the whole of the vanadium in half-an-hour.

C. A. Allen³ describes the vanadium deposits in the Caballos Mountains, New Mexico. The ore consists of vanadinite or vanadate of lead, and the development of the deposits and the treatment of the ore are dealt with.

J. O. Clifford⁴ also describes the deposits of vanadium in the Caballos Mountains, New Mexico.

Meteorites.—S. Meunier⁵ states that a meteorite which fell recently near Alexandria shows a remarkably crystalline structure, and consists principally of fragments of hypersthene (83·34 per cent.)

¹ *Mining and Engineering World*, vol. xxxv. p. 912.

² *Engineering and Mining Journal*, vol. xcii. pp. 1287-1288.

³ *Mining and Scientific Press*, September 23, 1911.

⁴ *Mining and Engineering World*, vol. xxxv. pp. 857-858.

⁵ *Comptes Rendus*, vol. cliii. pp. 785-787.

united by a cement soluble in hydrochloric acid. The hypersthene shows the macle structure, and contains inclusions of ilmenite. Analysis gave:—

	Per Cent.
SiO ₂	47.40
Al ₂ O ₃	0.69
Fe ₂ O ₃	20.80
CaO	15.20
MgO	14.61
K ₂ O }	0.05
Na ₂ O }	0.85
MnO	
Total	99.60

W. P. Hadden¹ states that a mass of meteoric iron weighing 596 lbs. was found about 1906 at Currant Creek, 22 miles south-west of Cripple Creek, Colorado. It shows no Widmanstätten figures on a polished and etched surface. Analysis gave:—

	Per Cent.
Fe	89.793
Ni	9.999
Co	0.554
Mn	0.054
Cr	0.048
Cu	} traces
P	
CaO	
MgO	

Its specific gravity was 7.9394.

A tabulated collection of 125 published analyses of meteoric stones is given by O. C. Farrington.² A table is also given showing the average composition of 318 meteoric irons, and the average of all meteorites, both stones and irons.

II.—IRON ORE MINING.

Shaft Sinking.—E. M. Heriot³ discusses the relative merits of various shapes for shafts. They may be either rectangular, oval, or circular, and the prevalence of any one type in certain districts is largely due to custom. Rectangular shafts have comparatively few advantages, and the adoption of circular shafts is urged both on the score of safety and economy.

Explosives and Blasting.—Taffanel⁴ and Dautriche discuss the methods of firing explosives when blasting in mines. One cartridge containing fulminate is usually arranged so as to explode several cartridges containing safety explosive only. Some experiments are

¹ *Proceedings of the Colorado Scientific Society*, vol. ix. pp. 79–80.

² *Field Museum of Natural History*, Chicago, 1911, Geological Series, vol. iii. pp. 195–229.

³ *Engineering and Mining Journal*, vol. xcii. pp. 1283–1285.

⁴ *Comptes Rendus*, vol. cliii. pp. 823–825.

described, the results of which show the most advantageous arrangement of the fulminating cartridge with respect to the others.

Equipment of Iron Ore Mines.—J. Liston¹ describes the electric power equipment at the iron ore mines of Witherbee, Sherman & Co., Port Henry, New York. Alternating current generators and induction or synchronous motors are used for practically all power purposes. There are some small motor-generator sets supplying direct current for magnetic separators and for locomotive haulage, but the total capacity of direct current motors is less than 100 horse-power, whereas the generating plants with a combined output of 4475 kilowatts serve alternating current motors totalling more than 5500 horse-power.

G. E. Edwards² describes the equipment of the Chapin mine of the Oliver Iron Mining Co. situated in the south-western part of Dickinson county at Iron Mountain, U.S.A.

Timbering in Iron Ore Mines.—H. Lakes³ deals with the timbering of metal mines through running and swelling ground.

F. L. Burr⁴ describes the method of square-set timbering as carried out at the Vulcan Iron Mines, Michigan.

Methods of Mining Iron Ore.—A short account is given⁵ of the Styrian Erzberg and the method adopted for the working of the ore. The ore is essentially a basic carbonate, containing on the average 38·7 per cent. of metallic iron. The mountain of ore presents the appearance of a vast staircase, the ore being continuously shovelled away on each level.

The methods of mining in vogue at the Biwabik Mine, the oldest mine on the Mesabi iron range, are described and illustrated by C. A. Tupper.⁶ The deposits now being worked dip to the south about 10°, and have a depth varying from 50 to 300 feet. Almost solid seams of hard ore cover several acres in a stretch, the intermediate layers being pure taconite and "paint" rock. By proper selection a good smelting mixture can be obtained of the average composition: Bessemer: iron, 55 per cent.; silica, 5·50; phosphorus, 0·045; non-Bessemer: iron, 51·50; silica, 6·0. Six shovels are used, each with a dipper capacity of 3 cubic yards. The breaker is the largest ever built, being a No. 24 Allis-Chalmers machine with a 48-inch opening, the object of its employment being to avoid reblasting and to permit handling of rock which could be loaded by steam shovels and hauled to the crushing plant in cars of larger size than those previously employed. The crusher is of the gyratory type, and as the steam

¹ *Iron Trade Review*, vol. I. pp. 649–653.

² *Mining and Engineering World*, vol. xxxvi. pp. 499–501.

³ *Ibid.*, vol. xxxv. pp. 1156–1157.

⁴ Paper read before the Lake Superior Mining Institute; *Mining and Engineering World*, vol. xxxvi. pp. 65–67.

⁵ *Stahl und Eisen*, vol. xxxii. pp. 297–303.

⁶ *Engineering and Mining Journal*, vol. xcii. pp. 1043–1045.

shovels handle pieces of ore weighing up to 7 or 8 tons, provision has been made for any pieces that might fall across the receiving opening in such a way as to obstruct the access of the material to the crushing throat. Details of the construction of this breaker and sectional drawings are given.

H. C. Estep¹ reviews the developments of mining operations on the Mesabi, Vermilion, and Cuyuna ranges.

R. W. Vallat² gives an account of the Newport iron mine at Ironwood, Gogebic County, Michigan, with special reference to the methods of working employed and the system of mine surveying in vogue.

C. Dixon³ deals with the open-cut mining of brown hæmatite in Alleghany and Craig counties, Virginia.

He also describes⁴ the methods of mining brown hæmatite iron ore that are peculiarly adapted to the conditions existing at the Low Moor mines, Virginia.

Haulage of Iron Ore.—A. Thunblom⁵ describes a compressed-air locomotive suitable for the transportation of ore.

C. Hanocq⁶ continues his mathematical investigation of the conditions under which aerial ropeways should be installed and worked, and gives formulæ for the guidance of engineers engaged in this class of installation.

The aerial ropeway installed at the Orconera Iron Company's Mines in Biscay, in the north of Spain, is described and illustrated.⁷ The system is a modification of the Bleichert apparatus.

Ore Handling.—A description is given⁸ of the new ore dock erected at Allouez, Wisconsin, which is claimed to be the largest in the world. It is equipped with 151 double ore pockets with a capacity of 325 tons each, and is capable of loading into a single vessel about 9500 tons of ore in twenty-five minutes.

K. Baumgarten⁹ illustrates several types of gates for ore shoots, pointing out that ease of manipulation and handling of the ore depends upon uniformity in its size. One of the most useful types is the arc gate. Any ore shoot gates should be exceedingly strong to withstand the hammering action of the ore in its passage down the shoot.

J. S. Cox¹⁰ describes the ore loading appliances installed at the port of Nima Nima, on the south-west side of Cuba, near Santiago de Cuba, for loading ore from the Ponopo Manganese Company's El Cuero iron

¹ *Iron Trade Review*, vol. I, pp. 26-36.

² *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 903-921.

³ *Mines and Minerals*, vol. xxxii, pp. 483-484.

⁴ *Ibid.*, pp. 553-554.

⁵ *Bihang till Jernkontorets Annaler*, 1911, pp. 917-920.

⁶ *Revue Universelle des Mines*, Series IV., vol. xxxvii, pp. 1-50, 185-234.

⁷ *Ibid.*, vol. xxxviii, pp. 117-121.

⁸ *Iron Trade Review*, vol. I, pp. 190-196.

⁹ *Engineering and Mining Journal*, vol. xcii, pp. 740-741.

¹⁰ *Iron Age*, vol. lxxxviii, pp. 753-755.

mines. The problem to be solved was the transport of ore estimated at 250,000 tons close to the Carribean Sea, but nine miles by water and twenty miles by land from the nearest available port. A combination of a number of principles was devised, of which the cantilever was the controlling factor. The capacity of this plant to deliver ore to vessels is regulated by the speed of the conveyor, which travels 650 feet per minute, and the volume of feed to which the roller feeders are adjusted. At first it delivered 700 tons per hour, but this has now been increased to nearly 800 tons per hour.

C. A. Tupper¹ describes the modern methods of handling iron ore at the various mines in Spain.

R. D. Williams² describes the largest iron ore carrying steamer on the Great Lakes. This vessel (the *Schoonmaker*) has a capacity of 15,000 tons.

Grading Iron Ore.—B. F. Rice³ describes the grading of dry and granular material, according to size or bulk of particle, without screens, and advocates the use of the McKesson screenless sizer to provide a cheaper and more efficient method of sizing such material than is afforded by any screening device.

Economics of Ore Mining.—J. R. Finlay⁴ deals with the methods for valuing ore properties, with special reference to the hard ore, soft ore, and Swanzey districts of the Marquette Range, and to scattered low-grade mines of other ranges. The logical position to take in regard to undeveloped mineral lands is that whatever values they may be proved to contain will be realised as soon as the mine is developed, and therefore the State loses nothing in the long run by exempting such land from taxation. L. Fraser⁵ likewise deals with the valuation of ore, and gives a scheme for estimating the amount of ore in a stope. This can be ascertained by plotting two new factors on a stope map, which gives better results than the old method of estimating the amount of ore by taking widths only.

History of Mining.—K. Nishio⁶ gives an account of the history of mining in Japan. In the early mythology of Japan the tradition is recorded that Ishikoridome, a smith, was the first to smelt copper. Records extending from the first year of the Emperor Jimmu, 660 B.C., to the conquest of Korea by the Empress Jingu, A.D. 200, show that swords and mirrors were made early in those days, but no definite records occur of other metallic products beyond the fact that when the Empress Jingu conquered Shiragi, a province of Korea, the king of that country promised an annual tribute of eighty vessels loaded

¹ *Mining and Engineering World*, vol. xxxvi. pp. 107-111

² *Iron Trade Review*, vol. 1. pp. 83-86.

³ *Metallurgical and Chemical Engineering*, vol. ix. pp. 627-628.

⁴ *Engineering and Mining Journal*, vol. xcii. pp. 749-752.

⁵ *Ibid.*, pp. 802-803.

⁶ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 103-124.

with gold, silver, and other treasures. Records relating to the iron industry are meagre. The smelting of magnetic sand was commenced about the year 1266 at Sugatini Mine, Idzumo, and the art of making swords, which seems to have been prosperous as far back as the ninth century, greatly improved at about this period. A mine map dated 1695 is preserved at the Tokio Imperial University.

III.—MECHANICAL PREPARATION.

Iron Ore Crushing.—An illustrated description¹ is given of an electrically driven iron ore crushing machine at the Biwabik Mine, Minnesota, which has a capacity of 1000 tons an hour.

Washing Iron Ore.—C. A. Tupper² gives an illustrated description of the ore washing plant of the Oliver Iron Mining Company. The plant is situated about three miles from the company's mines, on the shore of Trout Lake, opposite Coleraine, Minnesota, and is equipped with electric drive, and is capable of dealing with 1000 tons per hour. The chief feature is the use of the Overstrom table, this being the first time it has ever been adapted to the concentrating of iron ore. It has a patented head motion which advances mineral particles very rapidly, rocking arms being employed for the purpose. The table top rests on four long rollers, which extend the whole width of the table. It is a diagonal table, with the top placed diagonal to the line of reciprocation. Each of these Overstrom tables has a capacity of 350 lbs. of concentrates per hour.

The iron ore washing plant of the Orconera Iron Ore Company, Limited, near Bilbao, is described by C. A. Tupper.³

Drying Iron Ore.—A recent test of drying wet iron ore with a Ruggles dryer at the Pequest Company's No. 3 Mine, Buttsville, New Jersey, gave an efficiency of 89.05 per cent. The dryer was installed in the open, and was driven by a vertical steam-engine, which operated the dryer as well as the fan. The results of a series of five ore-drying tests carried out at this mine are given.⁴

A description has appeared⁵ of an experimental Atlas ore-drying plant erected at the Hollister mine, near Crystal Falls, Michigan. The apparatus has a capacity of approximately 400 tons per twenty-four hours, and dries from 14 to 15 per cent. down to about 4 per cent. It consists of a revolving steel cylinder, about 5 feet in diameter and 30 feet long, set at an incline toward the discharge end, and with lifting blades for cascading the material in its passage toward that

¹ *Iron Trade Review*, vol. I. pp. 387-390.

² *Mining and Engineering World*, vol. xxxv. pp. 949-954.

³ *Ibid.*, vol. xxxvi. pp. 107-111.

⁴ *Iron Trade Review*, vol. xlix. pp. 1060-1061.

⁵ *Iron Age*, vol. lxxxviii. p. 682.

end. The cylinder is enclosed in a steel casing like a boiler setting, with a furnace at the front and a fan which draws the heated air from it through suitable inlets in the cylinder and into direct contact with the ore as it passes toward the rear. The design is such that the air at its highest temperature and greatest velocity is brought in contact with the ore in its wettest state; and these are gradually lessened in degree, until at the discharge end there is practically no heat or fan suction remaining and very little moisture in the material. This elimination of the air suction at the rear of the cylinder obviates the necessity for a dust chamber, and the dried ore falls by gravity, through the open end, to an elevator. The shape of the air inlets, coupled with the cascading effect, prevents any leakage from the cylinder during the passage of the material.

Concentration of Iron Ore.—H. Louis¹ discusses magnetic methods of concentrating iron ore. He deals with the principles upon which magnetic concentration depends, and describes the various separators which may be used on an industrial scale. The author has been successful in concentrating Cleveland iron ore by this method.

The utilisation of fine iron ores and residues is dealt with,² and various processes for the concentration of low-grade ores are described. The early method adopted was to mix the fine material in a pug mill with some binder, such as clay, and form the mixture into blocks or briquettes in moulds by hand. The briquettes were then air dried, or, in the later plants, placed on floors below which steam was passed, and finally stacked in large kilns and roasted by means of a series of coal fires carried in hearths placed at intervals along the walls of the kilns. This comparatively crude method was followed by a modification of the Hoffman regenerative type of kiln which is frequently used for the burning of clay bricks. The nodulising process which is used to a modified extent in this country and in America consists of a long tubular furnace, about 100 to 125 feet in length and 7 to 10 feet internal diameter, made of riveted steel plates lined with firebrick. The tube is mounted on rollers at a slope of about 1 in 10, and is heated by means of producer or blast-furnace gas. The material to be dealt with passes into the top end of the furnace, when, owing to the slope and the rotary motion, it slides down the tube and the fine particles adhere together, forming nodules varying in size from that of a pea to a walnut. At the lower end of the furnace the temperature is sufficiently high to cause the particles to sinter together, forming a hard product with a capacity to absorb water amounting to about 6 per cent. of their weight. Sulphur is reduced to about 0.1 per cent. In the Gröndal process the material passes to suitable mechanical presses, by means of which it is formed, without any addition of binding material, into briquettes usually

¹ *Journal of the West of Scotland Iron and Steel Institute*, vol. xix. pp. 206-244.

² *Iron and Coal Trades Review*, vol. lxxxiv. pp. 92-93.

having the dimensions of $6 \times 6 \times 3$ inches. The briquettes are stacked in two layers on to bogie cars, which stand on rails running past the presses to the tunnel-shaped kilns. The kilns, which range in length from 150 to 200 feet, are built of firebrick. The width of the tunnel is such as to allow the cars to pass through with a minimum clearance of about 2 inches between the cars and the sides, so that the hot gases shall have as little opportunity as possible of damaging the ironwork. The kilns are filled by a continuous row of cars abutting together end to end. The cars are passed into the kiln at the rate of about three per hour by means of a push-bar actuated by an endless chain revolving in the centre of the track outside the kiln. The process is a continuous one, the time taken to produce finished briquettes from the raw material being roughly eight hours. The briquettes produced, owing to the oxidising nature of the flame and the free draft, have an extremely low sulphur content, usually ranging below 0.5 per cent., and the iron exists invariably in the hematite form. The porosity is about 15 per cent., and little trouble appears to be experienced from disintegration into powder during transit.

H. Comstock¹ describes a large iron ore concentrating plant at Mineville, Essex County, New York. The group of magnetite mines in this locality produce 1,000,000 tons of high-grade ores and concentrates annually. The three principal ore bodies are Old Bed, Harmony, and Barton Hill. The concentrating plant is divided into two sections, either of which may be run independently of the other. The current for the magnetic separators is obtained from a motor-generator set consisting of a 75-horse-power 440-volt constant-speed induction motor directly connected to a 50-kilowatt 125-volt direct-current generator.

The crude ore from the Harmony Mine contains about 51 per cent. of iron, 28 per cent. of silica, and 0.2 per cent. of phosphorus. After the concentrating process the concentrates average 64 per cent. of iron, 0.08 per cent. of phosphorus, and about 9 per cent. of silica, forming a coarse granular product ideal for blast-furnace use. The tailings average about 10 per cent. iron and 60 per cent. silica. The iron recovery is thus from 96 per cent. to 97 per cent. The capacity of the mill on 64 per cent. concentrates is 100 tons of crude ore per hour, but when middlings are being made the capacity is considerably greater. The power consumption per ton of crude ore is about three kilowatt hours. This includes all the primary crushing and all handling after the ore leaves the skips. In addition the mill is equipped to produce a special high-grade product of the following analysis:—

	Per Cent.
Iron	71.00
Phosphorus	0.017
Silica	1.80
Alumina	0.20

¹ *Iron Trade Review*, vol. xlix. pp. 825-829.

These concentrates are used chiefly in the manufacture of electrodes for arc-lamps.

The iron ore concentration and briquetting plant at the Sydvaranger Iron Mines in Norway is described and illustrated by A. Udhaug.¹

Briquetting of Iron Ore and Flue Dust.—J. A. A. Auzies² gives details of a method of briquetting iron ore and treating fine residues with milk of lime or by adding about 3 per cent. of quicklime to the iron oxides, and subsequently moistening the mass so as to form a workable paste. It is an advantage to add to the iron oxides about 10 per cent. of fine wood sawdust. After the briquettes have been made they are raised to a temperature of 1200° to 1500°, which brings about calcination of the mixed hydrate of lime and iron, and at the same time burns out the sawdust incorporated in the mass, thus conferring on the briquettes the necessary porosity. Experiments were also carried out with magnesium or calcium chlorides. To a mixture of the ore with sawdust or coke dust and a little lime or magnesia a 10 per cent. solution of magnesium chloride is added in sufficient quantity to form a plastic mass, which is subsequently compressed and dried by heating. Thus treated, briquetted ores satisfy all the necessary requirements of a good briquette.

J. W. Richards³ describes the Schumacher briquetting process. The process rests on the observation of the fact that blast-furnace flue dust, while possessing of itself no binding properties, acquires such if mixed with a very small amount of certain salt solutions. In practice 5 to 10 per cent. of its weight of magnesium chloride or calcium chloride solution is mixed with the dust, imparting to it the property of setting within a short time and forming a hard cemented briquette. A plant has been installed at Johnstown, Pennsylvania, with a capacity of 250 tons of briquettes per day, and an illustration of a Brück-Kretschle press for the Schumacher process, installed at Seraing, is given. A briquette made of flue-dust absorbed 11·5 per cent. of its weight of water, which represents a porosity of 27 per cent. After drying, the briquettes become exceedingly hard. The solution added appears to act as a catalytic agent.

N. V. Hansell⁴ deals with the briquetting of iron ores, with special reference to the Gröndal process, which is fully described and illustrated.

W. S. Landis⁵ deals with the agglomeration of fine materials, and divides the agglomeration processes into two groups, in one of which certain properties of the material are utilised to obtain the desired coherence, and in the other coherence is obtained through the addition of a foreign substance or binder. A good briquette should be porous, and one of the greatest drawbacks to the nodulising process is that the

¹ *Iron and Coal Trades Review*, vol. lxxiv. pp. 161-163.

² *Revue de Métallurgie, Mémoires*, vol. ix. pp. 35-36.

³ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 545-556.

⁴ *Ibid.*, pp. 557-575.

⁵ *Ibid.*, pp. 527-532.

nodules are non-porous, and therefore difficult to reduce. Disintegration should not follow the exposure to water vapour. Briquettes should not disintegrate when heated to redness, and in no instance should they contain a binder such, for instance, as a sulphur compound, which might exert a harmful influence on the furnace product.

The briquetting of fine flue-dust is discussed by F. A. Vogel.¹ In the United States this dust usually contains 20 per cent. of coke and over 40 per cent. of iron, and a ton of flue-dust represents a material loss. The processes described for sintering and briquetting such flue-dust are the Huntington-Heberlein pot process, the Gröndal briquetting process, the Dwight-Lloyd process, the Greenawalt process, the Pioneer process, the Ronay process, and the Schumacher process. The latter does not use a binder properly so called, but is based on the latent cementing materials present in fresh flue-dust, which are made active by the presence of a small amount of a catalytic substance. The process is inexpensive, and is extensively used abroad; while the briquettes made by it have given highly satisfactory results.

E. Holzhütter² gives an account of the method recently patented by L. Weiss for the briquetting of ores and of flue dust. Lime is used as the initial binding material, and after the briquette has been moulded it is treated with carbon dioxide under pressure, whereby the lime is converted into chalk. This yields a very strong yet porous briquette, particularly suitable for blast-furnace practice.

J. Mehrtens³ discusses the manufacture of briquettes by the aid of high pressure. Illustrations are given of the different types of presses used by German firms.

Bencke⁴ gives a critical review of modern methods of briquetting iron ore.

A description is given⁵ of the method employed for briquetting fine iron ores without the use of a binder by the Alquife Mines and Railway Company, Ltd., at Guadix, in the province of Granada, Spain.

IV.—METALLURGICAL PREPARATION.

Dwight and Lloyd Process of Sintering.—B. G. Klugh⁶ discusses the application of the Dwight and Lloyd process of sintering fine materials. A plant for the purpose is in operation at Birdsboro, Pennsylvania, and the results have been highly satisfactory. The finely divided material is intimately mixed with the amount of carbon

¹ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 533-544.

² *Stahl und Eisen*, vol. xxxi. pp. 1539-1543.

³ *Ibid.*, vol. xxxii. pp. 135-143.

⁴ *Erzbergbau*, January 15, 1912, pp. 20-21.

⁵ *Mines and Minerals*, vol. xxxii. pp. 237-238.

⁶ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 507-526.

required to produce the sinter. The mixture is then moistened and deposited in the machine in a uniform layer, the upper surface of which is ignited by a small flame of intense local heat, the combustion of the intermixed carbon being effected in a progressively downward direction by a current of air flowing in the same direction through the permeable mass. The character of the sinter produced depends wholly on the material, and is unaffected by the rate of sintering or of the velocity of the air current. Diagrams illustrative of the process are given. Several thousands of tons of sinter have been produced at the Birdsboro plant and used in the blast-furnace, and the sinter has shown itself a superior and beneficial addition to the blast-furnace charge. Taking off the ore and putting on the sinter has the same influence on the fuel consumption as would result from taking off entirely that amount of ore-burden. A wider application of the process is now suggested, whereby a solution of the problem of the conservation of mineral resources may be obtained. When the process is conducted with a proper proportion of moisture, proper ignition, proper mixture and distribution on the machine, there should be practically no fines. The product, although sufficiently magnetic to be attracted by an ordinary magnet, is not as magnetic as the unsintered material. The agglomeration of the ore particles is due mainly to the formation of ferrous silicate, and to a smaller extent to that of a calcium silicate.

Concentration of Iron Ore by Roasting.—J. O. Handy¹ and J. M. Knoté have carried out tests on the concentration and purification of iron ore high in silicon by roasting in a rotary kiln. The ore contained 4.01 per cent. of sulphur, and consisted of 32.6 per cent. of magnetite, 27.1 per cent. of siderite, 7.5 per cent. of calcite, 10.8 per cent. of magnesite, 2.5 per cent. of oxide, and 6.3 per cent. of silica. The results of the tests, with a rotary kiln, 70 feet long, similar to a cement kiln, show that roasting in such a kiln fired with powdered coal will efficiently desulphurise iron ore high in sulphur.

The results also indicate that the kiln should be at least 125 feet long, so as to give a zone 30 feet long at 1100°–1200° C., preceded by a zone 20 feet long at 900°–1100° C.

¹ *Journal of Industrial and Engineering Chemistry*, vol. iii. pp. 723–730.

REFRACTORY MATERIALS.

Physical Properties of Refractory Materials.—F. A. J. Fitzgerald¹ summarises the results of eight years' research work on the problem of obtaining suitable refractory materials. The materials on which investigations were carried out were alundum, crystolon (silicon carbide) obtained in two forms—crystalline and amorphous—magnesia, and lime. Alundum is made by purifying and fusing bauxite in an electric furnace, and is produced in two forms, white and brown, the former being the purer. White alundum has a melting-point between 2050° and 2100° C., and its linear coefficient of expansion is 78 by 10⁷. The heat conductivity is much higher than firebrick and the specific gravity is 3·9 to 4. Alundum bricks have been made for furnace roofs, and have withstood temperatures that destroy silica brick in five or six hours. In steel furnaces, however, the results have not realised the expectations held, and experiments have clearly shown that while alundum will successfully resist the temperature of the electric steel furnace roof, there are difficulties in the way of using it for that specific purpose, as the action of the lime vapours arising from the intensely heated basic slag used in the furnace is injurious.

Crystolon is a silicon carbide and its use was foreshadowed by Benjamin Talbot, who prepared it in an amorphous form, which is the first stage in the formation of crystalline silicon carbide. Silicon carbide in the form of carborundum has given satisfactory results for furnace linings, but amorphous silicon carbide is not a good heat insulator, and the crystalline-carbide, or crystolon, is a better refractory material for many purposes. The coefficient of expansion by heat is much less than that of silica, and the heat conductivity is higher than that of alundum. Experiments have been made in its use for the roofs of electric furnaces, in which crystolon brick was found to afford a perfectly satisfactory material. Its electric conductivity at high temperatures makes a special construction necessary, and although there is a considerable decrease in resistivity, with rise in temperature, the crystolon remains for most practical purposes an insulator. Crystolon bricks are somewhat expensive, but their moulding is a comparatively simple matter, and a satisfactory furnace has been designed for baking the brick.

¹ *Metallurgical and Chemical Engineering*, vol. x. pp. 129-132.

Magnesia, although an excellent refractory, has serious faults and is liable to crack at high temperatures. Electrically calcined magnesia is, however, less liable to this defect and does not absorb carbon dioxide.

Lime fused in the electric furnace has given interesting results and can withstand heating followed by sudden cooling. It resists exposure to moist air remarkably well and hydration proceeds very slowly, even when the material is boiled with water.

The Fusibility and Volatilisation of Refractory Materials.—O. Ruff¹ and O. Goecke have made experiments, in an electrical resistance furnace, on the fusibility and volatilisation of a number of refractory materials. A description of the apparatus employed, together with illustrations, is given.

The fusion temperatures of the following substances were ascertained:—

	Degrees Centigrade.
Uranium carbide	2425
Vanadium carbide	2750
Iron protoxide	1419
Iron sesquioxide	1548
Magnetic oxide	1538
Lime	1995
Alumina	2020
Chromium sesquioxide	2059
Uranium oxide	2176
Zirconium oxide	2500

For metals the following figures were obtained, the melting having been effected in an atmosphere of nitrogen under a pressure of about 5 millimetres or in a vacuum:—

	Degrees Centigrade.
Gold	1071
Manganese	1247
Chromium	1514
Platinum	1750
Molybdenum	2110
Tungsten	2575

In the course of the experiments the temperature of volatilisation of some of the substances was ascertained. Thus alumina, which melts at 2020° under atmospheric pressure, commences to give off vapour at 1600° under a pressure of 6 millimetres of mercury, and at 1750° the vaporisation becomes relatively rapid. A singular anomaly occurs in the case of lime. In an atmosphere of nitrogen and at atmospheric pressure, the crystalline needles of pure oxide sublime even at a temperature of 1740°, although fusion does not occur until a temperature of 1995° is reached. On the other hand, under reduced pressure, fusion does not occur until 2400° is reached.

Flow of Heat through Refractory Walls.—C. Hering² gives an exhaustive table of thermal resistivities which can be employed

¹ *Zeitschrift für angewandte Chemie*, vol. xxiv. pp. 1459-1465.

² *Metallurgical and Chemical Engineering*, vol. ix. pp. 652-654; vol. x. pp. 40-44.

to ascertain the flow of heat through bodies and from surfaces. In electric furnaces the economy of heat losses is of far greater importance than in fuel furnaces, on account of the greater initial cost of the energy. In fact, the cost of the energy is in many cases the criterion, hence a mere reduction of the losses may make the difference between commercial success or failure. It therefore becomes important in such cases to be able to proportion and design the walls of the furnaces so as to reduce these losses to the minimum necessitated by the particular conditions. The subject is classified under the following heads:—(1) Solid to solid. (2) Solid to gas. (3) Metal to water. (4) Water to metal to water. (5) Water to metal to air. (6) Gas to metal. (7) Gas to metal to water. (8) Gas to metal to gas. A table of reduction factors is given for each description of flow.

Fireclays.—Recent developments in the scientific study of the basis of a standard clay are dealt with,¹ and the views of the various investigators of this subject are summarised.

Firebricks.—K. Endell² discusses the composition of dinas rock for the manufacture of firebricks.

Expansion of Firebricks.—The volume of firebricks has been found by J. M. Organ³ to increase at the same time and at about the same rate as the sealed pore volume increased, and the author arrives at the conclusion that the permanent expansion of firebricks is due to the formation of an impervious bleb structure by “volatilising gases” in the glassy matrix formed by fusion.

Tests of Firebricks.—A. V. Bleininger⁴ and G. H. Brown state that under a load of 50 lbs. per square inch, the bricks being placed on end, no firebrick body can withstand a temperature of 1350° C. if the alkali equivalent be more than 0.225. Silica present in excess of the ratio $\text{Al}_2\text{O}_3 : 2\text{SiO}_2$, makes the alkali content more effective in fluxing power. Thus with 4.4SiO_2 failure under the load was brought about by 0.17 of alkali. Experiments at other pressures showed that most fire-bricks fail under 125 lbs. per square inch. Plastic clays are not necessarily detrimental if low in alkali. There is no relation between the crushing strength of a firebrick at 1300° C. and at ordinary temperatures.

Bauxite.—G. H. Ashley⁵ deals with the method of occurrence of bauxite and the method of working the bauxite mines of Tennessee.

¹ *Engineering*, vol. xciii. pp. 140-141.

² *Stahl und Eisen*, vol. xxxii. pp. 392-397.

³ *Transactions of the American Ceramic Society*, vol. xiii. pp. 602-611.

⁴ *Ibid.*, pp. 210-225.

⁵ Resources of Tennessee; *Mines and Minerals*, vol. xxxii. pp. 419-420.

Dolomite.—G. Lincio¹ states that a ferriferous dolomite was found about 4590 metres from the Italian end of the Simplon Tunnel, and was deposited in association with calcite and other minerals. It has a density of 3·003 at 14–15°, and on analysis gave—

	Per Cent.
CaO	29·61
MgO	12·94
FeO	12·99
CO ₂	44·72
Total	100·26

corresponding with the formula—



The mineral is crystalline, and contains many minute gaseous bubbles.

Graphite.—W. C. Arsem² proposes that the use of the term graphite be restricted to that allotropic form of carbon having the specific gravity 2·25–2·26. The author carried out an investigation to determine whether a pure form of carbon can be transformed into graphite by means of heat alone, or whether the conversion can be effected by adding, previous to heating, a quantity of mineral matter insufficient to form carbides with the whole of the carbon. With all the pure forms of carbon tested, it was found that, at 3000° C., the density reached a definite limit, which was not raised appreciably by the addition of small amounts of mineral matter, the end product being graphite in some cases and not in others. The impure carbons were found to behave in a similar manner, their properties after firing being characteristic for each variety and independent of the amount of ash present.

F. Cirkel,³ in dealing with the graphite deposits of Amherst, Quebec, describes the geological conditions existing, and the nature and extent of the deposits. He also gives his views as to the method of their formation.

Magnesite.—Kern⁴ describes the occurrence and utilisation of magnesite, the existing literature on which is scanty and often inaccurate. Amorphous or dense magnesite is an almost pure carbonate of magnesium containing up to 98 per cent. of carbonate of magnesia (MgCO₃). The generally accepted theory of its origin is that of the decomposition of serpentine and olivine rocks in contact with water charged with carbon dioxide. The chief European deposits of amorphous magnesite are in the island of Eubœa, and are worked by a Greek and an English company. On account of its great purity, Eubœan magnesite commands a higher price than that from other

¹ *Atti della Reale Accademia delle Scienze di Torino*, vol. xlv. pp. 969–988.

² Paper read before the American Electrochemical Society; *Metallurgical and Chemical Engineering*, vol. ix. pp. 536–537.

³ *Journal of the Canadian Mining Institute; Mines and Minerals*, vol. xxxii. p. 573.

⁴ *Glückauf*, vol. xlviii. pp. 271–276.

localities, the market price of burnt magnesite at present averaging £4 to £5 per ton. Other deposits of importance are at Kraubat in Styria, and at Frankenstein in Silesia, both of which formations occur as veins or pockets in the serpentine rock. The following are analyses of magnesite from these three best-known European localities:—

	Eubœa.	Frankenstein.	Kraubat.
	Per Cent.	Per Cent.	Per Cent.
Magnesia . . .	47.11	47.85	48.41
Lime . . .	0.51	..	..
Alumina . . .	0.20	..	..
Ferric oxide . .	0.20	..	..
Carbon dioxide	51.77	51.99	50.87
Silica . . .	0.20	trace	0.21

The temperature at which magnesite sinters depends upon the proportion of iron it contains. Magnesite with less than 2 per cent. of iron will withstand a temperature of 1600° to 1800° C., whereas with 2 to 7 per cent. of iron it will begin to sinter at 1400° C. On account of the high cost, amorphous magnesite is very rarely sintered before use.

Crystalline magnesite is of a white or grey colour, and its texture may be either finely or coarsely crystalline. It never contains the same proportion of magnesia as the amorphous magnesite, and always contains a proportion of iron sufficient to facilitate sintering, by which its preparation on a large scale is cheapened. The burnt product is sufficiently refractory where temperatures of 1500° to 2000° C. are not exceeded; but in any case the ferric oxide in the raw magnesite should never exceed 8 per cent. Various types of shaft furnaces are used for the burning of crystalline magnesite, the commonest until lately being the Lezelius—named after its inventor. Recently chamber furnaces, fired with producer-gas, have been used, capable of a daily output of 10 tons. The consumption of coal is high, half a ton of brown coal of 4000 calories being required for 1 ton of burnt magnesite. If the raw material is friable, as in some of the Hungarian works, rotating tube furnaces, similar to those for the production of Portland cement, are used. The type of furnace, in fact, is a very important point in the burning of magnesite. The method of the preparation of the product for use in the construction of metallurgical furnaces, and the qualities which serviceable magnesite should possess, are considered.

Attention is drawn¹ to the fact that a revolving tube furnace for the calcination of magnesium has been used for two years in Nyustya, Hungary, with very satisfactory results.

¹ *Stahl und Eisen*, vol. xxxii. pp. 25-26.

FUEL.

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I.—CALORIFIC VALUE.

Calorimetry.—R. Rieke¹ has made numerous tests on the melting-points of Seger cones 022-15, chiefly with regard to duration of firing and various types of kilns. Unlike metals and most chemical compounds, these cones have no definite melting-point. The chief factor is the duration of firing, which may affect the apparent melting-point by 60-100° C. If firing be prolonged, a cone will melt at a lower temperature. Cones 012a-1 are, however, an exception, as they melt with more difficulty in a slow fire. Although cones cannot be regarded as accurate pyrometers for temperature measurement, the advantage they possess over optical and thermo-electric instruments in the burning of pottery is that they are affected by the time factor as well as by the actual temperature attained.

A modification of the Berthelot-Mahler calorimetric bomb has been designed by C. Féry,² whereby the calorific power can be read directly from a millivoltmeter. The bomb is mounted in two discs of constantan, which connect it with the outer jacket of metal, the bomb thus becoming the hot junction and the jacket the cold junction of a thermo-electric circuit.

M. Brown³ describes methods of testing coal by means of the Lewis-Thompson and Roland-Wild calorimeters.

Pyrometry.—Leconte⁴ describes a new type of electrical pyrometer, in which a number of rods of zirconium oxide or other rare

¹ *Sprechsaal*, vol. xlv. pp. 726-729, 741-744.

² *Comptes Rendus*, vol. cliv. pp. 691-693.

³ *Practical Engineer*, vol. xlv. pp. 43-44.

⁴ Brussels Scientific Society; *Practical Engineer*, vol. xlv. pp. 806-807.

earths are mounted in a quartz bulb between two blocks of the same oxides. In upright tubes fused on to the quartz bulb there is placed a copper, silver, or some metallic alloy having a lower melting-point than the temperature to be observed. When the instrument is in use, these columns of metal melt and establish excellent electrical connection between the bulb and that part of the pyrometer which can be water-cooled; thence connection is by platinum or other suitable wires.

A description has appeared¹ of the Thwing pyrometer, the operating principle of which is the measurement of the total energy of radiation by means of the current generated in a sensitive thermo-couple by the radiation concentrated upon it. A conical mirror is employed for concentrating the radiation, and, in fact, to do away with the loss of time required for focussing and eliminating the error due to inaccurate focussing. The instrument is especially adapted for measuring the temperatures in open-hearth furnaces, and the range of temperature is unlimited in either direction.

In a lecture before the Sheffield branch of the British Foundrymen's Association, C. E. Foster² dwelt on the importance and value of inexpensive pyrometers for industrial use.

G. A. Shook³ deals with radiation pyrometry and enunciates the laws of black body radiation. The total radiant energy emitted from a black body is proportional to the fourth power of the absolute temperature, or $J = KT^4$ when K is a constant. Equations are also given, showing the relation between the temperature and the logarithm of the energy. Such an equation may be applied to any pyrometer using monochromatic light in which the luminous intensity can be varied in a continuous and determinate manner.

Heat Value of Fuel.—J. G. A. Rhodin⁴ deals with the determination of the calorific value of fuel, and compares the results obtained by means of calorimetric determinations and ultimate analyses. Suggestions for the carrying out of calorimetric tests are given.

Surface Combustion Experiments.—J. B. C. Kershaw⁵ describes a new method of using gaseous fuel for heating and steam-raising purposes, based on the old discovery by Sir Humphry Davy, that under certain conditions a mixture of a combustible gas and air, when forced into contact with a heated porous and refractory material or metal, could be burned without the production of any flame, yet with the maintenance of a very high temperature. W. A. Bone and C. D. McCourt have made experiments in this direction, and succeeded in obtaining fuel efficiencies equal to 95 per cent. of the actual heat value of the fuel gas used. An illustrated description is given of a simple form of apparatus for applying surface combustion to heating purposes. A

¹ *Iron Age*, vol. lxxxviii. p. 373.

² *Foundry Trade Journal*, vol. xiv. pp. 14-15.

³ *Metallurgical and Chemical Engineering*, vol. x. pp. 238-240.

⁴ *Engineer*, vol. cxiii. pp. 315-316.

⁵ *Metallurgical and Chemical Engineering*, vol. ix. pp. 628-630.

feed-mixing chamber is provided, through which gas and air pass. The amount of air used is in slight excess of that required for complete combustion of the gas. The mixture is forced into the mixing chamber and through the diaphragm, at the surface of which combustion occurs. The success of the method depends on the prevention of "backfiring" and the choice of a suitable refractory material. The gas-mixture burns without flame at the surface of the diaphragm, and maintains it in a high state of incandescence. Illustrations are given of the application of surface combustion to the heating of a muffle furnace and a crucible furnace. A charge of cast iron can be melted in one of these crucibles in ten minutes, starting with cold metal, the only temperature limit imposed being that of the melting- or decomposing-point of the refractory materials employed. Carborundum, which is widely used for furnace linings, and is considered highly refractory, is decomposed quickly into carbon dioxide and silica, in the interior of these furnaces, indicating that a temperature of 2000°C . has been approached.

Bone's Surface-combustion Boiler.—The experimental boiler used by W. A. Bone in his experiments on surface-combustion at Leeds University is described and illustrated.¹ Based upon these experiments, a boiler has been constructed for the Skinningrove Iron Company, which is also described. It is 10 feet diameter by 4 feet long, and contains 110 tubes of 3 inches diameter. It is fired with waste coke-oven gas drawn in by a fan producing suction equal to 20 inches of water. The gases escape to the atmosphere without a chimney.

A modification of the same steam generator is also illustrated and described.² With coal gas of a calorific value of 560 British thermal units per cubic foot, using 100 cubic feet per hour and air for complete combustion, and generating steam of 120 lbs. per square inch pressure, the waste gases were 240°C ., and when leaving the feed heater 95°C . The thermal efficiency of the boiler and heater exceeded 92 per cent., reckoned on the net calorific value of the gas, and the rate of evaporation exceeded 21 lbs. per square foot of heating surface per hour.

Utilisation of Low-grade Fuel.—Butow³ and Dobbelstein have presented further reports on their investigation of the value of low-grade fuel, giving results obtained by the gasifying of the small waste coke from coke-oven plants in gas-producers with stationary grates.

Carbon Dioxide Recorders.—E. A. Uehling⁴ describes a continuous carbon dioxide and temperature recorder and its application

¹ *Power*, vol. xxxv, pp. 80-81.

² *Mechanical Engineer*, vol. xxix, pp. 105-106.

³ *Gluckauf*, vol. xlviii, pp. 1-15.

⁴ Paper presented at the joint meeting of the American Chemical Society, the American Electrochemical Society, and the Society of Chemical Industry; *Metallurgical and Chemical Engineering*, vol. ix, pp. 656-659, 681.

for the purpose of ascertaining the efficiency of combustion. A number of formulæ are given for determining the heat carried off by the flue gases. The recorder consists of a carbon dioxide and temperature measuring machine connected by a small copper tubing to a standard type Uehling pressure and vacuum recorder, properly calibrated for carbon dioxide and temperature.

E. Müller¹ describes an automatic arrangement for the measurement of the carbon dioxide in flue gases. The principle of the apparatus consists in measuring the amount of heat developed in the absorption of carbon dioxide by potash liquor. The rise in temperature is ascertained by means of a thermo-electric couple.

Measuring Flue Gas Temperatures.—A method has been devised for the rapid determination of the temperatures of flue gases from boiler and other furnaces by means of pendants of fusible alloys of different compositions, which melt at different ranges of temperature when suspended in the flues.²

Measurement of Density of Smoke.—J. S. Owens³ describes a new method of measuring the density of smoke by comparing the opacity of the smoke with that of calibrated smoked glasses. Smoke density is defined as the amount of soot per unit volume. By careful construction an instrument can be made which gives a fair basis of comparison with a standard density.

II.—COAL.

Origin of Coal.—At a congress of German naturalists, Engler⁴ pointed out the importance of the decaying processes in the formation of coal and petroleum, both being products of substances which had no sufficient supply of oxygen to decompose completely into volatile products. Instead of such decomposition a petrification took place, with the result that small quantities of volatile products were formed, while the bulk of the matter was left in the shape of coal and petroleum or bitumen, according to the nature of the original organic substance.

J. Sim,⁵ in dealing with the geology of coal, discusses the "in situ" and "drift" theories of origin.

Glöckner⁶ has examined the brown-coal formations of the Southern Lausitz with the object of investigating their origin. The theories and researches of previous authors are quoted.

¹ *Zeitschrift des Vereines deutscher Ingenieure*, vol. lv. pp. 2169-2173.

² *Iron Trade Review*, vol. xlix. p. 794.

³ *Report of the British Association for the Advancement of Science*, 1911, p. 489.

⁴ *Petroleum Review*, vol. xxv. p. 463.

⁵ Paper read before the Scottish Federated Institute of Mining Students; *Iron and Coal Trades Review*, vol. lxxxiv. pp. 365-366.

⁶ *Braunkohle*, January 19, 1912, pp. 661-668, 677-685, 693-703, 709-712.

P. Krusch¹ discusses the geological conditions and origin of the coal-beds near Stockheim, in Germany. From the fact that the coal deteriorates in a very marked degree as its depth increases, the conclusion is deduced that the deposits are of allochthonic origin.

Geology of Coal.—T. Coventry² deals with the peculiar geological conditions that exist at the mines of the Charley Coal Mines Proprietary, Ltd., Queensland, Australia.

A. A. Steel³ describes the position, geology, and extent of the coal-fields of Arkansas.

Composition of Coal.—C. Catlett⁴ describes the occurrence of evansite ($\text{Al}_6\text{P}_2\text{O}_{14}\cdot 18\text{Aq}$) in coal obtained from the Big Seam, Columbia, Alabama. An analysis of this substance showed it to contain 10.33 per cent. of phosphoric anhydride and 36.33 of alumina, with traces of silica and a considerable quantity of lime and magnesia. One form in which phosphorus occurs in coal is evidently as a hydrated phosphate of aluminium; and any coal which shows the presence of a light-coloured resinous-looking material should be looked on with suspicion as being high in phosphorus.

J. A. P. Crisfield⁵ discusses the objectionable effect of moisture in coal and coke. Some kinds of coal absorb moisture more readily than others, experiments showing that the quantity of water removed from wet coal by evaporation during ten days' exposure in a normal atmosphere of 70° F. amounted to 14.6 per cent. of weight of the coal in one case. The author describes a works apparatus for determining moisture in fuel in which a sample is dried at 230° F., and the water is recovered in the liquid form and measured. One pound of the coal or coke is weighed into a jacketed tube provided with a screw-plug at each end, and steam under a definite pressure (corresponding to the temperature it is desired to use, preferably 230° F.) is passed through the jacket. The water vapour expelled from the coal or coke passes over and is condensed in a graduated glass tube surrounded by a cooling jacket; the graduations are so arranged that they can be read off directly. Determinations made with samples of dried coke to which definite quantities of water were added showed that the apparatus gives concordant results which are 0.13 per cent. lower than the true values. The apparatus can also be used for the determination of moisture in ores, and of water and light oils in tar.

F. F. Grout⁶ discusses the relation of texture to the composition of coal, giving field notes and analyses of seven samples.

W. D. Hornaday⁷ discusses the composition of the coals and lignites of Texas.

¹ *Gluckauf*, vol. xlvii. pp. 1593-1600.

² *Mines and Minerals*, vol. xxxii. pp. 273-275.

³ *Ibid.*, pp. 205-207.

⁴ *Bulletin of the American Institute of Mining Engineers*, 1911, p. 901.

⁵ *Journal of the Franklin Institute*, vol. cixxi. pp. 495-502.

⁶ *Economic Geology*, August 1911.

⁷ *Mining and Engineering World*, vol. xxxv. pp. 970-971.

Coal in Austria.—Panek¹ continues his description of the coal region of Rossitz-Zbeschau-Oslawa and of the development work that has already been carried out. Various collieries are now actively at work in these coal-fields. The district is also described by F. Franz.²

Coal in Bulgaria.—The coal deposits of Bulgaria are described by A. Blazy.³ The coal-field exists in the Balkans at Gabrova, which is worked by a Belgian Society. The coal-field will shortly be linked up by rail to the main railway system. An analysis of coal from the principal seam at these mines shows the following composition:—

	Per Cent.
Fixed carbon	58.9
Volatile matter	20.6
Moisture	1.6
Ash	9.9

The calorific value is 6996. The annual production from Bulgarian mines was returned in 1910 at 200,000 tons. Most of the coals are of a tertiary lignite origin.

Coal in France.—C. Barrois⁴ deals with the region of the coal deposits in the Nord coal-field, and describes the geological conditions which have led to the deposition of the seams.

Coal in Germany.—G. Fliegel⁵ describes the geology of the Rhine and, in particular, that of the Cologne region, with special reference to the occurrence of lignite. A map is given of the principal faults, and the tectonic movements of the field are deduced therefrom.

Kukuk⁶ deals in a similar manner with the lower Rhenish coal-field and the Westphalian coal-field; while W. Wunstorff⁷ deals with the productive coal-fields of the same region and of the Meuse.

Coal in Serbia.—A. Blazy⁸ gives an account of the iron ore resources of Serbia. On the banks of the Danube, and opposite to the Drenkova mines in Hungary, are the Dobra mines, where three coal-seams are worked by a Belgian Company. The composition of the coal is as follows:—

	Per Cent.
Carbon	77.58
Hydrogen	4.41
Oxygen and nitrogen	12.28
Moisture	3.05
Ash	2.68

¹ *Oesterreichische Zeitschrift*, vol. ix pp. 35-37, 50-52.

² *Ibid.*, pp. 57-60, 73-76.

³ *Mémoires et Compte Rendu de la Société des Ingénieurs Civils de France*, 1911, Part I. pp. 222-228.

⁴ Paper read before the International Congress of Mining, Metallurgy, Applied Mechanics, and Practical Geology, Düsseldorf, *Bulletin de la Société de l'Industrie Minérale*, Series IV, vol. xv. pp. 281-282.

⁵ *Ibid.*, pp. 270-272.

⁶ *Ibid.*, pp. 272-275.

⁷ *Ibid.*, pp. 276-280.

⁸ *Mémoires et Compte Rendu de la Société des Ingénieurs Civils de France*, 1911, Part I. pp. 207-222.

The calorific value is 7000 calories, and the coke yields 63·37 per cent. of coke. On the line from Belgrade to Nuch the Cenje mines occur. Here the deposits are of brown-coal intermediate between ordinary coal and lignite. The deposits are of interest geologically, and the composition of the coal is as follows:—

	Per Cent.
Carbon	58·12
Hydrogen	3·78
Oxygen and nitrogen	20·73
Moisture	13·32
Ash	4·05

The coke yield is 46·88 per cent. and the calorific value 4910 calories. Another important coal-field is that of Nichava, which is worked by a French Company. The coal is somewhat high in ash, 9·85 per cent., and the carbon amounts to 58·4 per cent. It has a coke yield of 48·88 per cent., and the calorific value of coal when dry is 5460 calories. Other deposits exist in the Timok Valley and at Zajecar. The output of coal from Servian mines in 1908 amounted to 293,125 tons, of which 179,098 tons were brown-coal.

Coal in Turkey.—Particulars are given¹ regarding the coal deposits in Turkey. The principal coal-fields are on the southern Black Sea coast, about 130 miles distant from Constantinople, and extend from Heraclea on the west to Filios on the east, a coast-line of about forty miles. These coal-fields are civil-list property, permission to work them being given only to Ottoman subjects. The most important of the mines is worked by the Heraclea Coal Company. Besides this well-known coal-field there are known to exist in Turkey several other deposits of importance, which have never been worked owing to lack of transport facilities.

Coal in Burma.—M. Stuart² describes the geology of the Henzada district of Burma. Coal occurs in the basal sandstone series of the eastern region. It is seen in outcrops, and the seam has been much shifted and affected by the faulting which has taken place in this region. The chief outcrops are at Posugyi, Kywezin, Hlemauk, and Kyibin. The Posugyi seam varies from 20 inches to 6 inches in thickness. Owing to the thinness of the seam, the steepness of its dip, and the contortion of the surrounding rocks, the occurrence does not appear to be of any economic value. The Kywezin outcrop is by far the most promising in the district. The coal crops out in the Nipasi stream, some six miles from Kywezin, and is also met with in the Theye stream, just to the north of the Nipasi stream. The seam appears to be about 10 feet in total thickness. The difficulties of working the coal are many. The coal itself is much slickensided, and has evidently been subjected to much crushing and movement, which is the probable explanation of the high percentage of fixed carbon that it contains. The country in which the seam occurs is much contorted

¹ *Board of Trade Journal*, vol. lxxv. pp. 224-225.

² *Records of the Geological Survey of India*, vol. xli. pp. 240-265.

and composed of exceedingly hard rock, often indurated with silica, and consequently the cost of sinking a shaft would be considerable. The seam in the Hlemauk outcrop is only 20 inches in thickness, and the coal is of very poor quality. It contains a very large percentage of iron pyrites. North of the village of Kyibin is a thin band of impure carbonaceous shale, which appears to be the same seam which crops out at Hlemauk, but, if so, it is here very much more impure and is quite worthless.

Coal in China.—T. T. Read¹ discusses the coal resources of China. A conservative estimate of the present production is 13,000,000 tons annually, notwithstanding that the resources are capable of enormous development. Analyses are given of coals from Fushun in the Manchurian coal-field, where the estimated resources are given as 800,000,000 tons, and of coals from Chili, where the production in 1909 amounted to 2,090,000 tons. Valuable coal-beds, estimated to contain over 22,000,000 tons per square mile of workable area, occur in Shansi. Both bituminous and semi-anthracite coal exist in this province, the coals being of high grade and, as shown by the analyses, low in ash and high in fixed carbon. A bibliography relating to the occurrence and mining of coal in China is given.

Coal in India.—According to E. H. Pascoe,² seams of coal of some importance have been discovered in the Namchik Valley, Upper Assam. The locality is three days' journey by boat up the Dihing river from Margherita. The seams were found in a small tributary of the Namchik about half a mile above its mouth. About 60 feet of coal is exposed here in five groups of seams. The coal is of excellent quality, and probably corresponds in horizon to that at Margherita and Ledo, which it resembles. The strata evidently belong to the Tertiary "Coal Measures" of Assam. The total thickness of coal is 60 feet, of which 5 to 6 feet is of poor quality, all of this occurring within a thickness of about 360 feet of strata.

Coal in Malay States.—In a report³ on the mineral industry of the Federated Malay States it is stated that coal has been discovered in the bed of a small stream in the state of Selangor. The results of operations show that the seam extends for more than half a mile. Several analyses have been made of the coal, and the tests show that it has a high percentage of moisture, a low percentage of fixed carbon, and a low percentage of ash.

Coal in the Philippines.—W. D. Smith⁴ reports on the coal resources of the Philippine Islands. The geological structure of these islands is such as to introduce many difficulties into the profit-

¹ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 293-343.

² *Records of the Geological Survey of India*, vol. xh pp. 214-216.

³ *Iron and Coal Trades Review*, vol. lxxxiii, p. 856.

⁴ Bureau of Science, Manila; *Iron and Coal Trades Review*, vol. lxxxiv, p. 9.

able exploitation of the coal-fields. Everywhere the strata are folded and faulted, and in many places shattered by earthquakes. Landslides are of frequent occurrence, because of steep slopes and excessive rainfall. The roofs of the seams are rarely found to be firm enough to stand without timbering. The geology is similar in many respects to that of the neighbouring islands of Formosa, Borneo, Java, and Japan.

Coal in Nigeria.—It is stated¹ that a further examination has been made of the extensive coal deposits at Udi in Southern Nigeria, which are found to stretch more than fifty miles to the north of that place. The tests carried out by the Government and the analyses at the Imperial Institute have proved that the surface samples give results equal to two-thirds those of the best Welsh coal. The lignite deposits to the west of the Niger are also very valuable, and those at Okpanam, only ten miles from Asaba, the Niger port opposite Onitsha, vary from 15 to 20 feet in thickness.

Coal in the Transvaal.—J. F. K. Brown² describes the coal-field of the Transvaal. The two main coal-fields at present being exploited in South Africa are in the Transvaal and in Natal. There is, however, a third relatively important district in Cape Colony called the Stormberg coal-field, but the quality of the coal and the working conditions are such as to preclude all idea of Stormberg becoming the centre of an important coal district. All three coal-fields are in what is known in South African geology as the Karroo system, which, although it is taken as corresponding approximately to the Carboniferous system of British geologists, is slightly younger in age. Permo-Carboniferous is the correct designation. In the Transvaal coal-field, as it is at present developed, two main districts are being worked, namely, the Springs, thirty miles from Johannesburg, and the Witbank, or Middelburg, eighty miles from Johannesburg. Witbank is the centre of the Middelburg district, and in and around this town there are situated about nine of the largest collieries in the Transvaal. Only one main seam of coal is worked, although four fairly workable seams are known to exist. No evidence has yet been collected sufficient to enable any correlation of the strata to be made between the different points where the existence of seams has been proved. Therefore, although the seams worked in the Transvaal vary from 20 feet around Witbank to 6 or 7 feet, or even less, in other districts, it is not possible to say how these different workings are related to each other, miles of country in many cases lying between them. The results of the analysis of the Transvaal coals go to show that in quality they do not approach the fuels produced in the British coal-fields: they are lower in heating power and higher in ash content. A number of

¹ *Board of Trade Journal*, vol. lxxv, p. 603.

² Paper read before the Scottish Federated Institute of Mining Students: *Iron and Coal Trades Review*, vol. lxxiv, p. 13.

average analyses are given below, taken from figures obtained on the ground :—

	Fixed Carbon.	Volatile Matters.	Ash.	Moisture.	Sulphur.	Calorific Value.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	64.76	23.48	9.96	1.78	0.80	12.46
2	59.08	29.02	10.10	1.80	1.38	12.16
3	63.72	23.46	11.08	1.74	0.70	12.33
4	62.18	26.28	9.94	1.60	0.75	12.40
5	59.50	23.75	14.52	2.23	0.70	12.12

Coal in Canada.—J. McEvoy¹ describes the coal deposits in the Brule Lake region of Alberta. They are situated on the east side of Brule Lake, on the main line of the Grand Trunk Pacific Railway, about 197 miles distant westward from Edmonton. Two claims have been staked, the Round claim containing 2560 acres and the Drinnan claim about 2500 acres. The total available coal within a depth of 2000 feet in the Round claim is estimated at 16½ million tons. No particulars are available of the quantity of coal on the Drinnan claim as the surface-covering is very deep and the coal does not outcrop. Analyses show the coal to be a very high-grade bituminous one, but with sufficient volatile matter to make it burn freely, and it is particularly well suited for locomotive and general steam use.

G. S. Malloch² furnishes the following notes on the new coal-field at Groundhog Basin, Skeena County, British Columbia. The coal-measures, so far as known, have a north-westward extent of at least seventy miles and a width at the southern end of thirty miles. The sediments have a thickness of upwards of 3000 feet, but contain coal in commercial quantities near the top and bottom only, though there are a few thin seams in the intermediate beds. The upper horizon contains seven seams with thicknesses varying from 2 to 6 feet, and, so far as is known, is limited to an area of twenty square miles. The lower horizon contains at least three seams 4 to 6 feet thick, and extends over most of the area occupied by the coal-measures. This coal is anthracitic in character. Some of the seams are high in ash, but from one of them some excellent analyses have been obtained. The basin is faulted considerably, and there are numerous local flexures associated with the faults.

R. R. Hedley³ describes the Copper River coal-field in the Skeena district of British Columbia.

Coal in the United States.—W. W. Atwood⁴ describes the coal resources of the Alaska peninsula. The best-known outcrops in the

¹ *Canadian Mining Journal*, vol. xxxiii, pp. 155-158.

² *Transactions of the Canadian Mining Institute*, vol. xv, Part I.

³ Address before the Western Branch of the Canadian Mining Institute, February 15, 1912; *Canadian Mining Journal*, vol. xxxiii, pp. 207-208.

⁴ *United States Geological Survey, Bulletin No. 467*, pp. 96-120.

Herendeen coal-field are near the head of Coal Valley and in the valley of Mine Creek. Coal is also exposed near the head of the next valley east of Coal Valley and at several places about the margin of the volcanic tuffs farther east, while still other outcrops have been reported in tributaries of Lawrence Creek. The main coal-measures outcrop on the east shore of Herendeen Bay, about five miles north of Mine Harbour, in a locality known as Coal Bluff. Two beds of lignite have been found on the north coast of the coal-bearing peninsula, about nine miles east of Point Divide, and several other seams of lignite are exposed on the west shore of Herendeen Bay. In the Chignik coal-field the formation that contains the bituminous coal is of Upper Cretaceous age. The developed fields are at Chignik River, Whalers Creek, Thompson River, and north-west of Hook Bay. At Coal Harbour the coal-measures are of Eocene age, and are a portion of the Kenai formation. All the coal seen in this field is lignite in character, and though seams are numerous most of them are too thin to be of commercial value.

W. L. Fisher¹ records his observations on the Alaskan coal-field made on the occasion of an extensive journey through that territory. The coal is of great value, but its extent and character have been exaggerated. Much lignite and low-grade bituminous coal exists, but there are only two known fields of high-grade coal in Alaska—the Bering River field and the Matanuska. There is at present no available anthracite on the Pacific Coast except that of Alaska, so that an immediate demand might be anticipated for this kind of coal. The Matanuska coal-field has an area of seventy-four square miles, but its situation handicaps its development owing to the want of adequate transportation from tide-water to the Yukon.

S. R. Capps² describes the coal deposits of the Bonfield region of Alaska.

J. B. Dilworth³ gives an account of the Black Mountain district in South-east Kentucky. The area of the coal-field is approximately twenty miles long by eight miles broad, and its distance from the great industrial centres of the Atlantic sea-board and the Mississippi Valley, and its lack of rail and river transport, have prevented its resources from being practically developed. A description of the various beds is given. Chemically, the coals of the Black Mountain district are very pure, and are useful as gas and coking fuels. Analyses show them to contain from 36.06 to 39.19 per cent. of volatile matter with 53.4 to 58.92 per cent. of fixed carbon. The ash varies, being in some of the coals as low as 2.29, but rising in some of the eastern varieties to as high as 10.21. The sulphur varies from 0.65 to 1.27, but with washing this could be considerably reduced. Calorimeter tests of carefully selected samples from the best beds show about 14,000 British

¹ Paper read before the American Mining Congress, October 27, 1912; *Engineering and Mining Journal*, vol. xcii, pp. 934-935.

² *United States Geological Survey, Bulletin No. 480*, pp. 231-235.

³ *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 149-176.

thermal units per lb. of coal. Physically, the coals are hard, lumpy, and of the block type.

A. B. Reagan¹ describes the coal resources of the Jemez-Albuquerque region in New Mexico.

E. W. Shaw² describes the geology of the coal deposits of the Foxburg Quadrangle, Pennsylvania. Most of the coal-beds belong to the Allegheny formation. An estimate of the average thickness of coal in this region indicates that no less than one-fourteenth of the total volume of the formation consists of coal. Four beds are known to be workable over considerable areas. These are the Lower Clarion, Lower Kittanning, Lower Freeport, and Upper Freeport. On the whole the coals are of good quality, but partly on account of sulphur and other impurities they are of little value for coking purposes.

E. E. Smith³ investigates the character, quality, and relative values of the coals of the State of Washington.

Coal in Australia.—L. C. Ball⁴ has published a map and a detailed description of the Mount Mulligan coal-field in Queensland, its geology, deposits, and development.

Peat.—C. A. Davis⁵ estimates that there are 11,200 square miles of peat-beds in the United States which contain 13,000 million tons of workable peat. The author refers to previous attempts to utilise these peat deposits, and gives particulars of the experimental work of the Canadian Department of Mines, and of the latest methods employed in Canada for the economical development of the peat deposits in that country. The preparation of peat for the production of peat-gas is considered, and it is stated that with peat delivered at the producer at 8s. 6d. per ton, a horse-power year costs about 31s. 0d.

A description is given⁶ of the Strenge machine for the cutting, mixing, pressing, and spreading of peat.

III.—CHARCOAL.

By-product Recovery in the Distillation of Wood.—H. Bergstrom⁷ discusses the method of recovering tar, turpentine, acetic acid, and volatile oils, in the process of the manufacture of charcoal.

Spontaneous Combustion of Charcoal.—An interesting account is given⁸ of the results of experiments made to ascertain the suscepti-

¹ *Mining and Engineering World*, vol. xxxvi, p. 23.

² *United States Geological Survey, Bulletin No. 454*, pp. 40-66. ³ *Ibid.*, No. 474.

⁴ *Queensland Government Mining Journal*, August 15, 1911.

⁵ *United States Bureau of Mines, Bulletin No. 16*; *Power*, vol. xxxiv, pp. 915-917.

⁶ *Génie Civil*, vol. ix, p. 94.

⁷ *Värmlandska Bergsmanföreningens Annaler*, 1911, pp. 93-100, *Stahl und Eisen*, vol. xxxii, p. 540.

⁸ *National Physical Laboratory, Annual Report for 1911*, p. 86.

bility of charcoal to undergo spontaneous combustion. In these experiments 1 cubic foot of charcoal was exposed in an electrically-heated oven to temperatures which were kept constant within 1° C. by means of thermo-couples. An air space of about 3 inches was provided all round the charcoal, and the observations were made both with the oven kept tightly closed and with the charcoal exposed to air currents of regulated velocity. It was found that when flake charcoal was heated in currents of air varying from 5 to 62 cubic feet per minute for 1 cubic foot of charcoal, ignition occurred at temperatures of 96° to 110° C., but that at lower temperatures there were no indications of spontaneous heating. Exposure of the charcoal to a current of air containing 5 per cent. of sulphur dioxide caused spontaneous ignition to take place in the course of a few hours.

IV.—COKE.

Chemistry of Coke.—In a contribution to the chemistry of coke, W. Hempel¹ and F. Lierg show that coke contains silicides, which account for its hardness, and they also suggest that the presence of finely divided silica has much to do with the formation of coke: the silica being reduced, with formation of carborundum and ferro-silicon. It is also shown that part of the silicon in coke is combined with iron or carbon. The determination of nitrogen by burning the coke in a current of oxygen, and then analysing the mixture of oxygen, carbon dioxide, and nitrogen formed, yielded higher results than Kjeldahl's method, in some cases double the amount of nitrogen being found. Inorganic constituents play an important part in the formation of coke, and it should therefore be possible, by adding suitable ingredients, to produce a good coke from any coal, even from one which in the ordinary way is "non-coking." A long series of experiments proved this to be the case, as is shown by the following example: A mixture of 120 grammes of non-coking coal, 18 grammes of powdery coke obtained therefrom, 4.8 grammes of clay, and 8 grammes of pitch, dissolved in 18 grammes of tar, gave a coke with a crushing strength of 235 kilogrammes per 0.6 square centimetres. This coke had less than 10 per cent. of ash. Best quality cokes tested for comparison had a crushing strength of 86–109 kilogrammes per 0.6 square centimetre. The addition of clay, tar, and pitch, therefore, influences the quality of coke in the most favourable manner.

V. B. Lewes² deals historically with the various processes for the destructive distillation of coal, and discusses the thermal conditions existing during the carbonisation of coal and the possible improvements in carbonisation.

¹ *Zeitschrift für angewandte Chemie*, vol. xxiv, pp. 2044–2046.

² Four Cantor Lectures; *Journal of the Royal Society of Arts*, vol. ix, pp. 135–145, 171–180, 188–197, 216–226.

Coke Manufacture.—J. L. Sherrick¹ deals at length with the manufacture of bee-hive oven coke, and gives tables showing the analyses of coal and the resultant coke, and the chemical requirements for the various kinds of coke.

C. Still² discusses modern coking practice, including the treatment of coke-oven gases for the recovery of by-products, the constitution of the gases, and their value as a source of power and lighting.

B. J. Goodin³ discusses the characteristics of the coke made in the Pittsburgh district, the types of ovens used, their design, and methods of operation.

By-product Coke-Ovens.—A description is given⁴ of the coking and by-product plant at the Birley Collieries, Sheffield. The ovens are of the latest Semet-Solvay type. There are fifty ovens in operation, arranged in two batteries, and eight additional ovens in course of construction. The by-product plant provides for the recovery of tar and ammonia, but is now being altered to the direct-recovery system.

Wagner⁵ describes modern coke-oven installations with by-product recovery, making special reference to the indirect process for the recovery of ammonia and tar.

An illustrated description is given⁶ of the Simon-Carvés by-product direct-recovery process.

The recovery of benzene from coke-oven gases is dealt with,⁷ and a review of the industry is given together with a description of the apparatus used.

By-product Coke-oven Practice.—R. Gillon⁸ describes the precautions necessary in starting and stopping by-product coke furnaces. The drying and heating up of a battery of by-product coke-ovens is a delicate operation, and requires to be carried out in a gradual and uniform manner in order to avoid cracking of the bricks and of the joints. The best method of lighting up, charging, and working the coke-ovens is described. In shutting down, circumstances have been taken into consideration as regards the length of the stoppage contemplated, and every precaution must be taken to avoid the entry of air, with the resulting risk of explosion when recommencing work. Special precautions are also indicated when it is required to let the whole installation out.

Coke-oven Accessories.—A description⁹ has appeared of a combined coke pusher and leveller, recently put into operation at the

¹ *Iron Trade Review*, vol. I, pp. 59-67.

² *Gluckauf*, vol. XLVII, pp. 1509-1517, 1549-1558, 1600-1608.

³ Paper read before the Pittsburgh Foundrymen's Association, December 4, 1911; *Iron Trade Review*, vol. XLIX, pp. 1931-1932.

⁴ *Iron and Coal Trades Review*, vol. LXXXIV, pp. 48-49.

⁵ *Bergbau*, January 11, 1912, pp. 13-18, 45-48.

⁶ *Iron and Coal Trades Review*, vol. LXXXIV, pp. 98-99.

⁷ *Chemical Engineer*, vol. XIV, p. 448.

⁸ *Revue Universelle des Mines*, Series IV, vol. XXXVIII, pp. 106-116.

⁹ *Iron Trade Review*, vol. I, p. 390.

Tennessee Coal, Iron, and Railroad Company's coke-oven plant at Cory, Alabama.

A description is given¹ of the electrical equipment of the Koppers-by-product coke-oven installation at Gary, Indiana.

Coke-oven Gas for Heating Open-hearth Furnaces.—A. P. Scott² describes the use of coke-oven gases for heating open-hearth furnaces. Recent work in this direction is reviewed, and the results obtained at Kattowitz, Hubertushutte, Seraing, and Sydney, British Columbia, are criticised. Most of the evidence serves to show that the most economical method for the disposal of the surplus gas of the by-product coke-oven is to utilise it as a fuel in the open-hearth furnace, and it has been shown to be perfectly practicable to use the gas either alone or mixed with producer gas. The furnace tonnage is increased, and the furnace life is not materially impaired. Recorded experience in this direction seems to be confined to Kattowitz and Seraing. It is unfortunate that the method employed at Hubertushutte for introducing the oven gas into the furnace has not been described, but it is understood that the mixing of the two gases is regarded as essential from the point of view of safety, the producer gas being lighted first and the oven gas introduced subsequently into the current of producer gas. Against these two successes must be placed the failure recorded at the works of the Dominion Iron & Steel Company at Sydney, the causes of which are discussed.

O. Simmersbach³ deals with the utilisation of coke-oven gas or a mixture of this and blast-furnace gases in the open-hearth furnace during the production of steel. It is claimed that:

- (a) A higher working temperature is produced, and hence a greater yield.
- (b) More uniform combustion obtains, which means less waste of gaseous fuel.
- (c) There is no need for a producer plant.
- (d) Fewer repairs are needed for the furnace top.
- (e) The coke-oven gas is much cheaper than producer gas.

V—LIQUID FUEL.

Origin of Petroleum.—E. Coste⁴ points out some of the geological and physical fallacies to which the theory of the organic origin of petroleum has led its supporters. Even very fossiliferous strata, supposed to be so full of organic life, contained, when finally deposited, only the remains of the hard calcareous or silicious parts of the

¹ *Iron Trade Review*, vol. xlix. pp. 1093-1097.

² *Iron Age*, vol. lxxxviii. pp. 538-540.

³ *Stahl und Eisen*, vol. xxxi. pp. 1993-2000, 2094-2100.

⁴ *Institution of Mining and Metallurgy*, Bulletin No. 85.

organisms from which no petroleum could possibly at any time be produced; and, on the other hand, petroleum as a general rule are not associated with fossils, which are found everywhere and in strata of every age absolutely devoid of petroleum (except in very rare cases of subsequent infiltration and replacement).

W. Ipatiew¹ has repeated Cloez's experiments² with a view to throwing light on the mechanism of the formation of petroleum, and has investigated the products of the action of dilute hydrochloric acid on various kinds of cast iron. It is found that, in addition to hydrogen, the gases contain a considerable amount of saturated hydrocarbons, but only a small quantity of olefines. No saturated open-chain hydrocarbons are contained in the liquid products, but only ethylene hydrocarbons and the higher fractions contain small amounts of what are probably polymethylene hydrocarbons. The author inclines to the theory of the formation of petroleum according to the organic as opposed to the mineral hypothesis.

C. Engler³ extends his theory of the formation of petroleum from organic remains, and refers to the results of his recent work in conjunction with Routala and Halmai regarding the formation of the different types of natural petroleum from a common source.

Hirschi⁴ considers that the hydrocarbon substances in the earth are derived from marine fauna which at some period were totally destroyed by the sudden eruption of gases due to submarine volcanic action.

C. L. Breger⁵ discusses the various theories put forward with regard to the origin of petroleum.

Composition of Petroleum.—M. A. Rakusin⁶ gives results obtained by fractionated distillation, showing the comparative composition of corresponding classes of oil from different localities.

I. C. Allen⁷ and W. A. Jacobs give in a series of tables the results of the analysis of a large number of samples of petroleum from different oil-fields in the San Joaquin Valley, California.

Oil-shale in Yorkshire.—According to J. B. Cohen⁸ and C. P. Finn, analyses of a dark-brown semi-solid material obtained from the Haigh Moor seam of the Hemsworth Collieries showed that the substance consisted of a mixture of liquid and solid paraffins.

Petroleum in Austria.—It is stated⁹ that the petroleum deposits of the Sloboda-Rungorska district of Galicia are contained in deep

¹ *Journal für praktische Chemie*, vol. lxxxiv. pp. 800-808.

² *Comptes Rendus*, vol. lxxviii. p. 1565.

³ *Petroleum*, vol. vii. pp. 399-403.

⁴ *Petroleum* (Berlin), October 18, 1911, pp. 62-63.

⁵ *Mining and Engineering World*, vol. xxxv. pp. 1219-1221, 1321-1324.

⁶ *Petroleum* (Berlin), December 20, 1911, pp. 288-289.

⁷ Department of the Interior; *Bureau of Mines, U. S. A., Bulletin* No. 19, pp. 1-46.

⁸ *Journal of the Society of Chemical Industry*, vol. xxxi. pp. 12-14.

⁹ *Petroleum Review*, vol. xxv. p. 293.

layers of coarse-grained sandstone up to 100 feet in thickness, which envelope a saddle-shaped base formed mainly of red schists of Eocene period. All geological indications at Sloboda point to a rich second petroleum stratum at a lower depth.

Petroleum in Russia.—P. Stevens¹ and A. E. R. Mc'Donell² describe the development of the mineral oil industry of the Caucasus.

Petroleum in Burma.—M. Stuart³ reviews the different series of rocks which crop out in the Henzada district of Burma from the point of view of their oil-bearing possibilities.

Petroleum in China.—Engler⁴ and Hoeffler describe the petroleum districts in China. Oil is found in the province of Kan-su, at the base of the Nanschang mountains, and in the province of Schen-Si, about 100 miles south-west from the missionary station Hsiao-tschao and the town of Ning-tiao-ling. Sources of salt water, gas, and petroleum have been known for a long time in the central part of the province of Sz-Tschwan, and it is reported that oil of an excellent quality is found at Fu-tochan-fu, on the River Min-ho.

Petroleum in India.—C. E. Capito⁵ describes the oil-wells of Assam. The first recorded discovery of petroleum in the Assam Valley was made in 1825, and borings were made in 1865 but were subsequently abandoned. By the construction of the Assam Railway and Trading Company's line through the district in 1882 a fresh impetus was given to enterprise, and in 1888 an outcrop of oil was discovered at Digboi, eight miles north of the Buri Dehing, in the Tippam range. Since 1888 thirty wells have been sunk in this area to depths varying from 500 to 2300 feet, and it is unique that although the yield is small not one of those wells is yet exhausted. After describing briefly the physical features and geological formation of the district, the author proceeds to give a full account of the method of drilling the wells, of the difficulties encountered in boring loose strata and sand, and of the means employed for raising the oil. The chief trouble in working the wells is that, on account of the high percentage of paraffin in the oil, the wells paraffin up, and the sand not having a free outlet collects below the paraffin and stops the flow of oil. The paraffin has to be cleared out with a sand-pump, which is a long and tedious operation.

Petroleum in Canada.—H. W. Le Messurier⁶ reports that deposits of oil-shale have been traced at Deer Lake, in Newfoundland,

¹ *Board of Trade Journal*, lxxvii. pp. 177-178.

² *Ibid.*, pp. 236-237.

³ *Records of the Geological Survey of India*, vol. xli. pp. 240-265.

⁴ "The Geology and Production of Petroleum"; *Petroleum Review*, vol. xxv. p. 393.

⁵ *Proceedings of the Institution of Civil Engineers*, vol. clxxxv. pp. 363-378.

⁶ *Board of Trade Journal*, vol. lxxv. p. 603.

for a distance of thirty miles. Analyses show that the shale contains a high percentage of oil.

Petroleum in the United States.—W. W. Atwood¹ describes the petroleum resources of the Alaska peninsula. Petroleum is known to occur in the vicinity of Cold Bay, on the east side of the peninsula, near the southern entrance to Shelikof Strait. Some drilling has been done, but it has not proved either the presence or the absence of oil of a commercial quality. It appears, however, that the geological data at hand warrant the continuation of investigations.

The progress of the Californian oil industry is described by M. L. Requa.² A new and important oil-field has been opened out at Midway. This field has produced the famous Lake View gusher, which is credited with a total production of over 8,000,000 barrels. The estimated production in 1910 of the Californian fields was 75,000,000 barrels, but the oil-producers of California as a whole did not apparently realise the real cost of production.

A. F. Lucas³ gives an account of the geology of the sulphur oil-fields of the Coastal Plain and the discovery of sulphur oil in that region. The oil is heavily saturated with sulphuretted hydrogen and sulphur dioxide. Sulphurous gases are also obtained in the vicinity.

R. L. Blatchley⁴ describes the Oakland City Oil-field, Pike County, Indiana. The pool is approximately four miles long and two miles wide at its widest place. The oil was first produced in 1908. The average production is about 10 barrels a day per well, and there are 201 producing wells.

L. L. Wittich⁵ deals with the history and geological conditions of the oil district of Oklahoma, and gives figures showing the quality and quantity of the output.

M. J. Munn⁶ describes the geology of the oil and gas fields of the Foxburg Quadrangle, Pennsylvania. He also describes⁷ those of the Carnegie Quadrangle.

G. D. James⁸ describes the San Juan oil-field in south-east Utah. The extent of the field has not yet been determined, but may include the reservations of the Navajo and the Pah-Ute Indians in New Mexico and Arizona in the south, as well as the country north through Moab and in the direction of the Green River. This region is practically unexplored. The history of the oil discoveries may be traced back as far as 1901, when samples from seepages gave results of sufficient promise to lead to drilling. On account of the practically

¹ *United States Geological Survey, Bulletin No. 467*, pp. 120-124.

² *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 377-386.

³ Address before the New York Section of the Society of Chemical Industry, December 15, 1911; *Metallurgical and Chemical Engineering*, vol. x. pp. 80-82.

⁴ *Report of the Indiana Department of Geology and Natural Resources, 1910; Engineering and Mining Journal*, vol. xcii. p. 937.

⁵ *Mines and Minerals*, vol. xxxii. pp. 291-294.

⁶ *United States Geological Survey, Bulletin No. 454*, pp. 66-82.

⁷ *Ibid.*, *Bulletin No. 456*.

⁸ *Engineering and Mining Journal*, vol. xcii. pp. 1082-1084.

inaccessible situation of the lands, work was abandoned until 1907, when it was renewed further eastward and higher up stream, oil and water being reached at 170 to 220 feet. More recently deeper wells have been sunk, the greatest depth being 1700 feet. The view is expressed that the San Juan oil-field is a deep-well field, and that 3000-foot holes must be considered as a basis of development. The geology of the region is described, and analysis of oil from the oil city wells shows 12·5 per cent. of naphtha by volume; 21·2 per cent. of light burning oil; 19·2 per cent. of heavy burning oil; 43 per cent. of heavy oils, and loss of 4·1 per cent. on coking.

Petroleum in Argentina.—F. G. Rule¹ reports the discovery of petroleum in the north of Argentina, which has been confirmed by the result of the Government survey. The district in question lies to the north-east of Oran, in the province of Salta, and close to the Bolivian frontier. The Department of Mines is satisfied that the petroleum field is an extensive one, and that the oil is of good quality and near the surface.

Petroleum in New Zealand.—The geology of the petroleum-bearing regions of New Zealand is dealt with.²

Earth Temperatures in Oil Regions.—Geothermic measurements made by von Höfer³ in oil-bearing strata show that in oil regions the intervals of depth at which the temperature rises 1° C. are unusually small, amounting only to 12 metres.

Use of Liquid Fuel.—J. Holden⁴ gives an account of the application of liquid fuel to the locomotives of the Great Eastern Railway Company. Owing to the difficulty of disposing of the tar produced at the Stratford works of the Company in the manufacture of gas for carriage lighting, experiments were made in 1885 with a view to its utilisation for steam raising. In two years the requirements of oil-tar for locomotive firing had outgrown the supply from Stratford, and the purchases amounted, five years later, to 15,000 tons per annum. Liquid fuel, as compared with solid fuel, could only be made to pay, however, so long as the maximum price did not exceed by very much twice the current price of coal. The theoretical evaporative capacity ranged from 17 to 21 lbs. of water per lb. of fuel, and the actual evaporation from 11·6 to 14 lbs. of water, the evaporative efficiency being from 66 to 72 per cent. A description of the oil-burning appliances is given.

R. G. Aston⁵ gives an account of liquid-fuel burning in the locomotives of the Tehuantepec National Railroad of Mexico. He de-

¹ *Board of Trade Journal*, vol. lxxv. p. 508; vol. lxxvii. p. 255.

² *New Zealand Geological Survey, Fifth Annual Report (New Series); Petroleum Review*, vol. xxv. p. 339.

³ *Organ der Bohrtechnik*, December 1, 1911, pp. 279-280.

⁴ *Proceedings of the Institution of Civil Engineers*, vol. clxxxv. pp. 340-345.

⁵ *Iron and Coal Trades Review*, vol. lxxxiii. p. 1015.

scribes the facilities for handling and storing the oil, the methods of burning it, and gives results taken from records of the monthly performances of locomotives.

E. W. Kerr deals¹ with the utilisation of oil as fuel in boiler furnaces, and discusses the main essentials for the best results in burning the oil.

E. Shackleton² discusses modern developments in the use of oil-engines and the advantages and disadvantages of internal-combustion engines using crude oil, with special reference to engines for marine propulsion.

H. R. Setz³ discusses critically the Diesel engine and its modifications, and considers some of the principles involved in the various methods of fuel injection.

Storage of Petroleum—F. W. Oatman⁴ describes a large concrete reservoir built at Coalinga, California, for the storage of petroleum.

Artificial Asphalt.—L. Perrenet⁵ describes the manufacture of artificial asphalt. A works for this purpose exists at Couvet, in Switzerland, in close proximity to the celebrated asphalt mines of the Val de Travers. The principle upon which the manufacture of artificial asphalt depends is the impregnation of powdered calcareous substances with bitumen. The calcareous material employed, which is very fine grained and friable, is obtained from the same geological formations as the asphalt deposits mined in the Val de Travers, and it is reduced to powder and mixed intimately with bitumen so as to form, on heating, a paste having the same consistency as that of natural asphalt. The question as to whether the artificial material is better or worse than natural asphalt can only be determined by experience extending over lengthy periods, but laboratory experiments have given excellent results. From a purely commercial point of view it may be pointed out that while the asphalt mines have to pay a royalty to the Canton of Neuchâtel of eight francs per ton of asphalt mined, the artificial asphalt works has to pay nothing for mining the material it employs. The bitumen used to mix with the lime is obtained from Austria and Holland. It is steam heated before being placed in the mixers.

¹ *Louisiana State University Bulletin* No. 131; *Engineering News*, vol. lxvii. pp. 584-585.

² Paper read before the Institution of Marine Engineers; *Mechanical Engineer*, vol. xxviii. pp. 274-278, 284-290.

³ *Journal of the American Society of Mechanical Engineers*, vol. xxxiii. pp. 1169-1200.

⁴ *Mining and Engineering World*, vol. xxxv. pp. 1007-1008.

⁵ *Revue de Métallurgie, Mémoires*, vol. ix. pp. 50-51.

VI.—NATURAL GAS.

Natural Gas in Transylvania.—The discovery of natural gas in Transylvania is described.¹ The gas is found at Kissarmas, about 50 miles from Kolozs-var and 250 miles from Budapest. Borings were made in 1909 with the object of finding deposits of potassium salts. At a depth of 22 metres emanations of methane were met with, and at a depth of 150 metres inflammable gas was given off, the quantities becoming considerable when a depth of 300 metres was reached. A shaft was put down, tapping a supply of 860,000 cubic metres daily, escaping at a rate of 190 metres per second. The calorific value of the gas was 8600 calories. The Royal Department of Mines is undertaking borings to ascertain the extent of the gas-bearing formation.

Natural Gas in the United States.—G. A. Burrell² states that the analysis of samples of gas collected from wells in various oil-fields of South California gave: Carbon dioxide, 1.0 to 30.4 per cent.; oxygen (three samples), 0.1 to 0.2 per cent.; total paraffins, 67.2 to 96.7 per cent.; nitrogen, 0.9 to 5.2 per cent.; methane, 54.2 to 88.0 per cent.; and ethane, 0 to 35.6 per cent. The heating value was 724 to 1240 British thermal units per cubic foot. None of the samples contained hydrogen, carbon monoxide, olefine hydrocarbons, or hydrogen sulphide.

Utilisation of Natural Gas.—K. Feldmann³ discusses various methods of utilising natural gas by combustion under steam boilers and in distilling apparatus. He describes various systems of burners, including those used in Caucasus and Galicia.

Conservation of Natural Gas by Liquefying.—I. C. Allen⁴ and G. A. Burrell propose a method for the conservation of natural gas which is being allowed to escape almost without restraint in the petroleum fields of America by liquefying the gases under pressure.

Transport and Storage of Natural Gas.—K. Feldmann⁵ deals with the natural gas that is emitted from the borings for petroleum in the Boryslaw-Tustanowice oil-fields, Galicia, and describes the pipeline that has been constructed for conveying the gas to the refinery at Drohobycz, 8½ kilometres distant.

T. R. Weymouth⁶ points out the most important problems in the production and transportation of natural gas, and outlines the methods

¹ Report of the French Consul-General at Budapest, June 8, 1911; *Annales des Mines*, Series IX, vol. i, pp. 257-258.

² *United States Bureau of Mines, Bulletin* No. 19, pp. 47-56.

³ *Petroleum* (Berlin), December 20, 1911, pp. 285-288.

⁴ *United States Bureau of Mines, Technical Paper* No. 10; *Metallurgical and Chemical Engineering*, vol. x, pp. 234-235.

⁵ *Petroleum*, vol. vi, pp. 2232-2235.

⁶ *Journal of the American Society of Mechanical Engineers*, vol. xxxiv, pp. 725-771.

of solution. He briefly discusses the properties of natural gas, and gives a table of analyses of gases produced in the principal fields of the United States, together with a formula connecting the heat value of the natural gas with its specific gravity. He also deals with the development of the original formulæ for the flow of gas in pipe-lines, the power required for compression and storage, and gives examples showing the general method of design of a transmission system.

Natural Gas Power-Station.—An electric power station driven by natural gas has been installed at Independence, Kansas.¹ The equipment consists of a 500-kilowatt double-acting Monarch engine, a 200-kilowatt double-acting Snow engine, and a 100-horse-power Westinghouse 3-cylinder engine, all driving alternators of different capacities. Under average conditions, during a thirty days' test, 1 kilowatt-hour was developed for 20 cubic feet of gas taken by the engines. The gas is brought from Oklahoma, and has a fuel value of 950 British thermal units per cubic foot.

VII.—ARTIFICIAL GAS.

Gas Producers.—K. Munzel² gives practical hints with regard to the working of the revolving-grate gas-producer, and points out that very satisfactory results may be obtained with it. It is essential both for the quality of the gas and the regular working of the producer that every portion of the fuel content shall contribute equally towards the production of gas. This is the case when the whole mass is equally permeable and the uppermost layer of fuel exhibits a uniform dull red glow. If dark patches occur, the "green" fuel, as it is termed, offers great resistance to the passage of gas and leads to irregular working. It is desirable that the producer be fitted with a suitable charging apparatus through which the fuel may enter and be deposited at will, either in the middle or round the sides according to requirements. This may be accomplished with a bell-and-cone arrangement fitted into a cylindrical casing in the roof of the producer. If the casing has a diameter of 1·2 metre the bottom of the bell may be 1 metre in diameter, so that a space of 10 centimetres lies free all round its lower edge. When the entrance is closed the bell fits tightly against the cone, and its lower edge should be about 15 centimetres from the bottom of the casing, which latter is flush with the vault of the producer. If now fuel is thrown into the cone and the bell lowered, say, 10 centimetres, the fuel strikes the cylindrical casing and rebounds into the middle of the producer. If the bell is lowered some 30 centimetres, however, its lower edge now projects into the broad vault of the producer, and the fuel falls out towards the circumference. Thus, by regulating the fall of

¹ *Electrical World*, vol. lxxi. pp. 1001-1003.

² *Stahl und Eisen*, vol. xxxi. pp. 1493-1497.

the bell, the fuel may be deposited at any desired place. Finally, back pressure must be avoided. Experience shows that if the pressure above the fire inside the producer does not exceed 4 or 5 centimetres of water, the conditions are most satisfactory.

An account is given¹ of the Kerpely high-pressure gas-producer. The main difficulties to be overcome in using fine fuels for gasification are (1) the greater resistance offered to the passage of the air-blast, and (2) the difficulty of reducing the non-combustible ash to the lowest minimum. The minimum size of the particles of fuel that can be used varies with the nature of the fuel. The problem is further complicated by the fact that many fuels splinter into yet smaller particles when introduced into the producer in consequence of the sudden gasification of moisture within their pores. The Kerpely gas produced is designed to reduce these difficulties to a minimum. The pressure of the blast ranges from 40 to 70 centimetres of water, the blast itself passing through a number of minute openings distributed over the cross-section of the producer. This results in complete combustion of the small particles of fuel. The ashes fall automatically into a bucket which requires emptying some two or three times each day. An interesting table is given showing the results obtained with various fuels.

F. Fielden,² in dealing with problems in bituminous suction-gas plants, states that in the earlier experiments with the down-draught type of suction-plants the air for combustion was charged with vapours in exactly the same way as now holds with anthracite plants; but it was found that although sufficient heat was obtained for making gas of effective and explosive power, yet the tarry volatiles and soot were deposited in the gas-supply pipes, and eventually found their way into the engine. Since it is necessary to pass a sufficient amount of vapour through the generator in order to produce good gas without the formation of an excessive amount of clinker, and to prevent the firebrick lining being burnt away, which would occur were air alone admitted, it becomes necessary to divide the functions of the suction bituminous producer into two distinct processes. First the coal must be coked, and, secondly, the coked fuel must be fed with the necessary air and vapour to produce good gas. The latter function is already attained in most suction-plants now on the market, and the former is one to which attention is now being directed. As in commercially successful bituminous suction-generators both functions should be combined, together with means for treating satisfactorily widely divergent qualities of coal, both caking and non-caking, containing quantities of ash varying from 5 to 40 per cent. and volatile matter varying from 16 to 40 per cent., some idea of the difficulty of the problems can be formed. Another trouble which, although present with suction-gas plants for anthracite and coke fuel, is intensified considerably with bituminous coal, is the question of ash and clinker.

¹ *Stahl und Eisen*, vol. xxxi. pp. 2140-2142; *Iron and Coal Trades Review*, vol. lxxmiv. p. 330.

² *Engineering*, vol. xciii. pp. 175-177.

With the large increase in the amount of ash resulting from the use of bituminous coal, it is absolutely essential that means shall be provided for removing such ash and clinker without causing any undue alteration in the working of the engine.

Particulars are given¹ of the working of four 10-foot Rehmann revolving-grate gas-producers at the works of Vickers, Limited, of Sheffield. These producers, each of which is capable of gasifying 20 cwt. of coal per hour, were laid down to supply gas for fourteen large gun-ingot and armour-plate heating furnaces.

Particulars are given² of the results obtained with two Hilger gas-producers with rotating grates installed at the works of Dorman, Long & Co., Limited, Middlesbrough.

F. Bauriedal³ describes the Kuppers rotary grate type of gas-producer.

A description has appeared⁴ of a gas-producer designed by E. Fleischer with the object of producing a gas having a temperature of 1000° C. and upwards for use in processes of a chemical nature, such as the reduction or fusion of metals, or for heating purposes. The fuel used for the producer is anthracite or coke.

An illustrated description is given of a gas-producer, designed by E. Dor-Delattre,⁵ which is provided with a rising and falling grate. The grate is carried by a plunger, and by means of this arrangement the coal can be wholly or partially raised without altering the size of the annular outlet for the cinders and ashes, which can be readily removed during the working of the producer. The raising and lowering of the grate causes the coal to be kept continually in motion, and stirs it up over the whole surface.

An illustrated description is given of a gas-producer designed by A. Folliet-Mieusset,⁶ with the object of obtaining a more uniform and adjustable distribution of the primary air introduced at the base of the producer.

A description is given⁷ of the Mathot suction gas-producer. The type of producer permits of the utilisation of low-grade fuel of the smallest size. The gas passing from the top of the producer to a bottom outlet superheats the steam given off by the water vaporizer before reaching the fuel bed, allowing a greater quantity of steam to be dissociated without cooling the gas.

C. M. Garland⁸ describes the equipment and general arrangement of bituminous coal-producers as designed for power purposes. The scrubbing apparatus is described in detail and the working results are considered. Particulars of the efficiency of the plant, composition of the gas, and operating costs are also given. Figures for the first cost and operating costs at full load for a 1200 brake-horse-power plant

¹ *Iron and Coal Trades Review*, vol. lxxxiv, p. 62.

² *Ibid.*, p. 252.

³ *Chemiker Zeitung*, vol. xxxv, pp. 1283-1284.

⁴ *Mechanical Engineer*, vol. xxvii, p. 606.

⁵ *Ibid.*, vol. xxix, pp. 155-156.

⁶ *Ibid.*, pp. 218-219.

⁷ *Power*, vol. lxxv, pp. 215-216.

⁸ *Journal of the American Society of Mechanical Engineers*, vol. xxiv, pp. 885-904.

are given in such a way as to make them applicable to different conditions of fuel and load.

Illustrated descriptions are given¹ of two underfeed gas-producers designed by A. E. Pratt, which are of the type in which the fuel is fed continuously or intermittently in an upward direction to a fixed point within the producer, whence it passes radially downwards over the grate to a peripheral discharge opening.

Gwosdz,² after tracing the development of the gas-producer, gives an account of modern producer design and practice, and of results obtained with various kinds of fuel.

R. H. Fernald³ and C. D. Smith describe various types of gas-producer plants for power purposes, including the suction, pressure, and down-draft types. The results of six years' investigation at St. Louis, at Norfolk, and at Pittsburg are reported.

C. Bone⁴ discusses the operation of gas-producers for the production of gas for steelworks.

In dealing with producer-gas, J. A. Weil⁵ discusses the design of the producer, and considers the chemical reactions that take place therein. He also deals with different types of producers and the plant for the purification of the gas.

An illustrated description is given⁶ of a fuel-charging device for gas-producers, designed by F. G. Smith and J. S. Atkinson. The apparatus consists of a hopper on the top of the producer, into which the fuel is charged, and from whence it is delivered through a revolving feeder, which distributes the fuel over the fuel bed. The apparatus is designed to act also as a crusher for large pieces of fuel, as well as a feeder and charger.

An interesting account of an explosion in a suction gas-producer plant, due to a leakage of air into the expansion-box, is given by M. Longridge.⁷

Meyer⁸ describes recent types of Pintsch gas-producers, and deals with the problem of burning coke breeze and coke dross, as well as cinders, from locomotive smoke-boxes.

Peat-Gas Producers.—Particulars are given⁹ of a peat-gas plant which has been in successful operation at Portadown, Ireland. The peat is air-dried, being cut from the bog and stacked during the summer. As cut, the peat contains about 85 per cent. of moisture, and during an

¹ *Mechanical Engineer*, vol. xxix. p. 426.

² *Gluckauf*, vol. xlvii. pp. 1559-1569.

³ *United States Bureau of Mines, Bulletin* No. 13, pp. 1-378; *Mining and Engineering World*, vol. xxxv. pp. 1120-1123.

⁴ *Chemical Engineer*, vol. xiv. pp. 378-380.

⁵ Paper read before the Manchester Association of Engineers, December 8, 1911; *Mechanical Engineer*, vol. xxviii. pp. 755-757.

⁶ *Mechanical Engineer*, vol. xxix. p. 325.

⁷ Annual Report of the British Engine, Boiler, and Electrical Insurance Company for 1910; *Mechanical Engineer*, vol. xxviii. p. 453.

⁸ *Journal für Gasbeleuchtung*, vol. lv. pp. 73-80, *Iron and Coal Trades Review*, vol. lxxxiv. p. 645.

⁹ *Engineering*, vol. xcii. p. 774.

average season this can be reduced by air-drying to 26 per cent. The plant consists of two producers of 200 horse-power capacity each, with coke-scrubber, tar-extractor, sawdust-scrubber, exhauster, and expansion-box. The gas produced has a value of about 140 British thermal units, and is similar to that produced from Welsh anthracite, but contains slightly less hydrogen. The approximate analysis of the peat is—water, 18·98 per cent.; volatile matter, 55·17 per cent.; fixed carbon, 24·75 per cent.; ash, 1·10 per cent. The ultimate analysis showed carbon, 44·6 per cent.; hydrogen, 5·42 per cent.; nitrogen, 0·97 per cent.; ash, 1·10 per cent.; moisture, 18·98 per cent.; and oxygen, by difference, 28·93 per cent. The cost of fuel per week for supplying an average load of 275 brake-horse-power, is £4, 5s., allowing 35s. per week derived from the sale of tar.

P. C. Percy¹ describes a peat-gas producer plant, consisting of a 300 horse-power engine and Heinze peat-gas producer, at the East German Exhibition at Posen.

Producer-Gas from Crude Oil.—H. A. Grine² publishes some notes on methods and devices for converting oil into gas, and gives an illustrated description of the Grine-Nelles producer for the manufacture of gas from crude petroleum.

By-Products from Gas-Producers.—A. Gwiggner³ points out that the economy of collecting ammonium sulphate and tar from gas-producers is, with the present prices of fuel and ammonium sulphate, more than counterbalanced by the cost of the extra fuel required to produce the same amount of heat as by the ordinary type of producer—at any rate, as far as Germany is concerned.

Application of Producer-Gas to Boiler Firing.—E. Schindler⁴ deals with the application of producer-gas to the firing of steam boilers.

Gas-Engines.—R. L. Streeter⁵ discusses the application of the internal-combustion engine in modern practice. Various types of gas and oil engines are described and illustrated, including the Diesel, the Corrington, and the Remington engines, using oil fuel, and the Westinghouse and Bruce-Macheth engines, using natural gas. Particulars of fuel consumption and efficiencies are given.

A. L. Hoehr⁶ gives particulars of his experience with gas-engines driven by blast-furnace gas at the works of the National Tube Company, McKeesport. The plant comprises two Allis-Chalmers twin-tandem, four-cycle gas-engines, with cylinders 32 inches in diameter

¹ *Power*, vol. xxxv. pp. 53-54.

² *Mining and Scientific Press*, vol. ciii. pp. 381-382.

³ *Stahl und Eisen*, vol. xxxi. pp. 2085-2088; vol. xxvii. 188-189.

⁴ *Ibid.*, vol. xxxi. pp. 1771-1773.

⁵ *Engineering Magazine*, vol. xlii pp. 185-205, 349-370, 560-576.

⁶ *Journal of the American Society of Mechanical Engineers*, vol. xxxiii. pp. 1089-1093.

by 42-inches stroke. Each engine drives a 1000-kilowatt Crocker-Wheeler direct-current generator, 250 volts at 110 revolutions per minute. They operate in parallel with four Allis-Chalmers steam units, driving 624-kilowatt Crocker-Wheeler generators. The gas-cleaning plant is also described.

C. A. Tupper¹ describes the new central-power system of the Royal Prussian Collieries in the mining district of Saarbrücken, which includes two electric generating stations, one equipped with gas-engines operated by the waste gas from by-product coke ovens, and the other with steam turbines.

An illustrated description is given² of a new type of 25 brake-horse-power suction gas-engine.

VIII.—COAL-MINING.

Shaft-Sinking.—Ehrenberg³ presents the results of some observations of the various effects of freezing the ground, during shaft-sinking by the freezing process.

Shaft-sinking by the Poetsch method of freezing is dealt with;⁴ reference being made to the determination of the direction of the bore-holes and the formation of the ice-wall and its resistance to pressure.

J. S. Franklin⁵ describes some interesting cases of shaft-sinking through difficult water-bearing strata.

R. G. Johnson⁶ describes the methods in general use for sinking and lining shafts of coal-mines in America.

Earth Pressures in Collieries.—Morin⁷ discusses the earth pressures in collieries. Their influence is felt in three ways—namely, in the weakening of the seams, subsidence of the workings, and in the evolution of mine gases. The pressures themselves may be regarded as derived from one of two sources—being due either to terrestrial movement or to the mining operations themselves.

Mine Supports.—R. B. Woodworth⁸ deals with the replacement of wooden mine supports by steel supports at the Dodson colliery of the Plymouth Coal Company, United States, and gives the comparative costs of the two installations.

S. L. Goodale⁹ describes and illustrates the method of timbering used in the mines of the H. C. Frick Coke Company.

¹ *Mining and Engineering World*, vol. xxxv, pp. 1255-1260.

² *Iron and Coal Trades Review*, vol. lxxviii, p. 1058.

³ *Bergbau*, October 12, 1911, pp. 645-647.

⁴ *Mines and Minerals*, vol. xxxii, pp. 245-246.

⁵ *Cassier's Magazine*, vol. xli, pp. 123-131.

⁶ *Mines and Minerals*, vol. xxxi, pp. 344-347.

⁷ *Comptes Rendus de la Société de l'Industrie Minérale*, 1911, pp. 604-605.

⁸ *Mines and Minerals*, vol. xxxii, p. 215.

⁹ *Ibid.*, pp. 195-200.

The question of proportioning mine pillars according to the strength of the coal is discussed, and the views of various authorities are given.¹

W. H. Hepplewhite² discusses the action and control of differently constituted coal roofs.

Use of Concrete in Mines.—Details are given³ of the ferro-concrete structures at the surface plant of the Harrington Collieries, Workington. These include cage-framing, cages, head-gear, slack-conveyor, banking-house, and gantries.

Electric Equipment of Collieries.—The two sections of the new French mining regulations dealing with the employment of electricity in mines have been published⁴ in English.

The electrical equipment of the Craighead and Bothwell Castle Collieries of W. Baird & Co. is described.⁵

A description is given⁶ of the electrical equipment of the Clock Face Colliery of the Wigan Coal and Iron Company.

R. H. Willis⁷ discusses the mechanical design of electrical plant in collieries.

Gas-Power in Collieries.—A. E. L. Chorlton⁸ discusses the use of gas-power for driving in collieries, and indicates two methods of obtaining gas for such purposes. In the first case there is the ammonia-recovery producer, using combustible nitrogenous material from belt-pickings, or tips, mixed, perhaps, with some coal; the whole of low market value, and producing a large amount of power-gas, and ammonium sulphate as a by-product. In the second case there is the by-product coke oven, using small coal and producing furnace coke, with many by-products and a considerable residuum of gas available for power and other purposes. The author then deals with the possible methods of application of gas-engines to the various requirements of the average colliery. These methods are four in number, namely: (1) the electric scheme; (2) the hydraulic scheme; (3) the pneumatic scheme; and (4) the mechanical or direct scheme.

Coal-cutting Machinery.—An account is given⁹ of the development of the use of coal-cutting and conveying machinery in mines, and the relation of the price of labour to the selling price of coal

¹ *Mines and Minerals*, vol. xxii. pp. 214-215.

² Paper read before the Midland Counties Institution of Engineers; *Iron and Coal Trades Review*, vol. lxxxiii. pp. 970-971.

³ *Iron and Coal Trades Review*, vol. lxxxiv. p. 572.

⁴ *Ibid.*, vol. lxxxiii. p. 896.

⁵ *Electrician*, vol. lxvii. pp. 939-940.

⁶ *Mines and Minerals*, vol. xxxii. pp. 270-271.

⁷ Paper read before the East of Scot. and Branch of the Association of Mining Electrical Engineers; *Iron and Coal Trades Review*, vol. lxxxiv. pp. 338-339.

⁸ Paper read before the Midland Institute of Mining, Civil, and Mechanical Engineers, December 5, 1911; *Mechanical Engineer* vol. xxviii. pp. 764-769.

⁹ *Electrical Review*, vol. lxxix. pp. 431-433.

and the effect of the application of machinery to coal-mining are considered.

F. C. Perkins¹ describes some modern types of English coal-cutting machines.

W. B. Shaw,² in dealing with coal-cutting machinery, gives a description of the rotary and percussive types of machines, and compares their relative advantages.

Methods of Working Coal.—Leprince-Ringuet³ describes the progress which has been made in coal-mining in the Pas de Calais during the last thirty-five years. In 1876 the production amounted to 3,000,000 tons, while the present production is over 10,000,000. The area of the coalfield worked has been considerably extended; the average depth of the beds has been increased by nearly 50 per cent., but, on the other hand, the seams worked have tended to become narrower. The output per workman employed has not increased in proportion to the general output; the daily yield per head in 1880 having been 900 kilogrammes, while in 1910 it was 1042. Special reference is made to the progress in winding-engines, pumping and ventilating machinery, and surface installations, such as washeries and coke ovens.

C. A. Tupper⁴ describes the system of coal-mining adopted by the Hartshorn & Patterson Coal Co. at Missionfield, Illinois. This consists of the application of a special type of revolving steam shovel which is required for the mining of an almost continuous layer of coal averaging about 4 feet in depth, with an overburden of 20 to 30 feet of earth.

An illustrated description is given⁵ of the method of longwall working employed in the mines of the Spring Valley Coal Company, Illinois.

F. L. Burr⁶ describes the method of square-set mining in use in the Vulcan mines, Michigan.

J. F. K. Brown⁷ describes the methods of working coal in the Transvaal collieries.

G. S. Caldwell⁸ describes the method of working at the Lai Heu Ho coalfield in the province of Ho-nan, in China.

Winding-Engines.—Moldenhauer⁹ considers the economic problems involved in winding from great depths. In consequence of the

¹ *Mining and Engineering World*, vol. xxxv. pp. 797-798.

² Paper read before the Manchester Association of Engineers, November 24, 1911; *Iron and Coal Trades Review*, vol. lxxxiii. pp. 879-882.

³ *Comptes Rendus de la Société de l'Industrie Minière*, 1911, pp. 503-506.

⁴ *Mining and Engineering World*, vol. xxxvii. pp. 59-60.

⁵ *Mines and Minerals*, vol. xxxii. pp. 451-454.

⁶ Paper read before the Lake Superior Mining Institute; *Mining and Engineering World*, vol. xxxvii. pp. 65-67.

⁷ Paper read before the Scottish Federated Institute of Mining Students; *Iron and Coal Trades Review*, vol. lxxxiv. p. 13.

⁸ Paper read before the Manchester Geological and Mining Society, May 14, 1912; *Iron and Coal Trades Review*, vol. lxxxiv. p. 806.

⁹ *Gluckauf*, vol. xlvii. pp. 1948-1961, 1981-1992.

increased weight of the winding-ropes, the moving masses which require to be accelerated or slowed down are so enormously increased that it becomes necessary to adopt every possible device for reducing their weight, or at least for neutralising their effect. It is shown by numerous diagrams and mathematical calculations in what respects the efficiency of winding plants can be improved for winding from depths of 1000 to 1500 metres both by steam-engines and by electric winding-engines.

The Society of German Engineers in 1907 appointed a committee to investigate the comparative cost of working and efficiency of steam-driven and electric winding-engines. The committee's report has now been published,¹ in which the experiments and their results are fully described.

W. Philippi² describes the principal types of electric winding-engines. The advantages and disadvantages of the various systems, and their efficiency, are compared, and the chief points to be borne in mind in calculating their economy are considered.

The relative advantages of electric motors and compressed-air engines for driving deep-mine hoists are discussed by K. A. Pauly.³

H. J. S. Heather⁴ discusses the safety of induction motors for driving winding engines. The advantage of the automatic cutting off of the current is problematical, and considerable harm may result from it.

The winding equipment at the Birley Collieries, Sheffield, is described⁵ and illustrated.

An illustrated description is given⁶ of a new method of electric winding at the Auchincruive pits of William Baird & Co., Scotland.

Winding Appliances.—J. Paul⁷ describes the Walker overwinding prevention-gear installed at the Løchgelly Iron and Coal Company's Mary pit.

J. Strachan⁸ describes the "Visor" controller for the prevention of overwinding.

Haulage in Collieries.—Paehr⁹ gives general results of experiences with mine locomotives in the collieries of the Dortmund mining district. The various types of locomotives in use are illustrated and described, and the working costs are shown.

Otte¹⁰ gives results of tests with naphtha-fired locomotives used for haulage purposes in the Dechen Colliery, in the Saar district, and presents calculations of the cost of haulage with such locomotives.

¹ *Gluckauf*, vol. xlvii. pp. 1629-1640, 1675-1681 *et seq.*

² *Elektrotechnische Zeitschrift*, vol. xxxii. pp. 1047-1050, 1084-1089.

³ *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 923-950.

⁴ *Electrician*, vol. lxxviii. pp. 177-178.

⁵ *Iron and Coal Trades Review*, vol. lxxxiv. pp. 48-49.

⁶ *Ibid.*, pp. 534-535.

⁷ *Transactions of the Mining Institute of Scotland*, vol. xxxiv. pp. 56-60.

⁸ Paper read before the Midland Branch of the National Association of Colliery Managers, March 10, 1912; *Iron and Coal Trades Review*, vol. lxxxiv. pp. 561-564.

⁹ *Zeitschrift für Berg-, Hütten- und Salinenwesen*, vol. lix. pp. 647-672.

¹⁰ *Ibid.*, pp. 739-768.

Wendriner¹ compares different methods of haulage under different conditions, and gives results of experience with mechanical haulage in the coal-mines of Upper Silesia.

W. C. Mountain² describes the different types of electric haulage that is used underground in collieries.

Ventilation in Collieries.—The new electrical fans installed at the No. 9 Pit of the Escarpelle Mining Company, Nord, France, are described by Lacroix.³ The fans themselves are of the Menet and Moyné turbine type, and take three-phase current at 5000 volts.

Lighting of Collieries.—E. Lemaire⁴ describes the Goulet safety-lamp, which is an incandescent lamp employing benzene as an illuminant. Its photometric power is 3·5 Heffner units. It is at once extinguished by cutting off the air-supply, and in practice has proved exceedingly safe, although it has not up to the present been very widely adopted.

An illustrated description is given⁵ of a new portable electric safety-lamp.

Gases in Mines.—R. Nowicki⁶ describes an apparatus for the detection of minute quantities of carbon monoxide present in mine gases. The test depends on the darkening of paper impregnated with palladium chloride in the presence of carbon dioxide, the length of time being an important factor in determining the result.

C. Moureu⁷ and A. Lepape have made analyses of five specimens of fire-damp collected under conditions excluding air. The results show the existence of a much higher proportion of helium to nitrogen than that existing in air. The nitrogen from one specimen contained no less than 13 per cent. of helium.

H. Briggs⁸ deals with the use of safety-lamps as a means of testing for fire-damp and black-damp.

W. H. Cunningham⁹ and C. R. Connor describe a method by which gas under pressure in coal-mines can be relieved by the use of bore-holes.

Coal-dust Experiments.—W. Galloway¹⁰ gives a review of the progress in coal-dust experiments carried out in Great Britain and abroad.

¹ *Zeitschrift für Berg-, Hütten- und Salinenwesen*, vol. lix, pp. 673–695.

² Paper read before the North of England Branch of the Association of Mining Electrical Engineers, *Iron and Coal Trades Review*, vol. lxxxiv, pp. 334–337.

³ *Comptes Rendus de la Société de l'Industrie Minière*, 1911, pp. 571–572.

⁴ *Annales des Mines de Belgique*, vol. xvi, pp. 623–636.

⁵ *Colliery Guardian*, vol. ciii, p. 76.

⁶ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. lix, pp. 587–588.

⁷ *Comptes Rendus*, vol. cliii, p. 847–849.

⁸ *Transactions of the Mining Institute of Scotland*, vol. xxxiv, pp. 84–99.

⁹ Paper read before the Kentucky Mining Institute, *Mines and Minerals*, vol. xxxii, pp. 409–410.

¹⁰ *Proceedings of the South Wales Institute of Engineers*, vol. xxviii, pp. 6–35.

The reports of J. Taffanel¹ and A. Durr on the recent French coal-dust experiments are republished in English.

J. Cadman² describes the equipment of the Bruceston coal-dust experimental station in the United States.

W. M. Thornton³ discusses the influence of the presence of gas on the ignition of clouds of coal-dust by single electric flashes.

I. C. F. Stattham⁴ gives a historical account of the coal-dust theory, and briefly describes the British, French, Austrian, and American experiments.

Explosions in Collieries.—An official report by Hollender⁵ is published on the explosion in the Radbod Colliery, near Hamm, in Westphalia, which took place in the night of November 11, 1908. At the time of the explosion 384 men were below ground, of whom only 17 escaped injury, the total number of fatalities being 348. The cause could not be definitely established, but is considered to be probably due to one of the benzene safety-lamps having become defective during use or having been given out in a defective condition.

J. Taffanel⁶ gives an account of the disastrous explosions which occurred in the West Stanley Mine and the Pretoria Mine in South Africa on February 16, 1909, and December 21, 1910, respectively.

The explosion which occurred in 1911 in a coal-mine at Briceville, Tennessee, by which 180 miners lost their lives, is discussed,⁷ and the cause of the disaster is explained.

Accidents in Coal-Mines.—G. B. Harrison⁸ deals with accidents in mines caused by falls of ground.

Storage and Heating of Coal.—H. C. Porter⁹ and F. K. Ovitz give an account of an investigation carried out by the United States Bureau of Mines on the deterioration and spontaneous heating of coal in storage. The authors put forward the following recommendations:—(1) Coal should not be piled more than 12 feet deep, nor in such a manner that any point in the interior will be more than 10 feet from an air-cooled surface. (2) If possible, only lumps should be stored. (3) Handling of the coal should be reduced to a minimum, in order to avoid production of dust. (4) Lumps and fines should be distributed on the pile as evenly as possible, care being

¹ *Colliery Guardian*, vol. ciii. pp. 227-228.

² Paper read before the North Staffordshire Institute of Mining and Mechanical Engineers, *Iron and Coal Trades Review*, vol. lxxxi. p. 976.

³ Paper read before the North of England Branch of the Association of Mining Electrical Engineers; *Iron and Coal Trades Review*, vol. lxxxiv. p. 253.

⁴ Paper read before the South Staffordshire Mining Students' Society, November 11, 1911; *Iron and Coal Trades Review*, vol. lxxxiii. pp. 806-808.

⁵ *Glückauf*, vol. xlviii. pp. 169-181, 209-218, 253-260.

⁶ *Annales des Mines*, Series X., vol. xx. pp. 363-446.

⁷ *Mining and Engineering World*, vol. xxxv. pp. 1223-1224.

⁸ *Transactions of the Manchester Geological and Mining Society*, vol. xxxii. pp. 186-199.

⁹ *Journal of Industrial and Engineering Chemistry*, vol. iv. pp. 5-8.

taken that lumps do not roll down and form air-passages at the bottom. (5) The coal should be rehandled and screened after two months. (6) External sources of heat should not be allowed near the pile. (7) The coal after mining should be "seasoned" for six weeks before storing in piles. (8) Alternate wetting and drying of the coal should be avoided. (9) Admission of air to the interior of the pile through interstices or porous foundations should be avoided. (10) Ventilation by pipes should not be attempted.

The Omaha Electric Light and Power Company have constructed a pit for storage of coal under water, the capacity being 10,000 tons, which is sufficient for a three months' operation of the company's plant of 13,000 kilowatts.¹ The structure is of reinforced concrete carried on piles, and the pit has an area of 100 × 116 feet, with a depth below water-level of 23 feet. A 5-ton crane of 145 foot span stretches over the pit and the track for coal trains alongside of it.

E. A. Harman² states that the deterioration of coal on stocking is greatest when the coal is first stacked, and gradually decreases until after a period of time it is practically negligible.

An instrument for determining the temperature of coal piles is described,³ the outstanding feature of which is a special boring tool.

Rescue Appliances.—The report is published⁴ of an investigation of rescue apparatus for use in coal-mines carried out by a committee of the South Midland coalowners.

R. Crawford⁵ describes the equipment and work of the Fife and Clackmannan Colliery rescue station.

The organisation of the mine rescue service of the State of Illinois is described by H. H. Stoeck.⁶

Sanitation in Collieries.—H. Kuss⁷ describes the measures adopted in Belgian mines to combat the spread of ankylostomiasis. During the years 1895–1896 the disease assumed grave dimensions, and a Commission was appointed to inquire into the extent of the epidemic, and sums of money were voted by the Provincial Council of Liège and Committees at Mons and Charleroi for the purpose of the investigation. Owing to the introduction of more sanitary measures in collieries the epidemic has been stemmed, and the occurrence of the disease amongst miners has fallen considerably.

A description is given⁸ of the systems of baths and dressing-rooms for miners adopted both in this country and on the Continent.

Some notes descriptive of lavatories and baths installed at various

¹ *Electrical World*, vol. lviii, pp. 884–885.

² *Journal of Gas Lighting*, vol. cxvi, p. 243.

³ *Iron and Coal Trades Review*, vol. lxxxiv, p. 169.

⁴ *Colliery Guardian*, vol. cii, pp. 415–417, 467–468.

⁵ Paper read before the National Association of Colliery Managers, December 16, 1911; *Iron and Coal Trades Review*, vol. lxxxiv, pp. 1–4.

⁶ *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 951–959.

⁷ *Bulletin de la Société de l'Industrie Minière*, Series IV, vol. xv, pp. 361–366.

⁸ *Iron and Coal Trades Review*, vol. lxxxiii, pp. 848–850, 886–887.

British collieries for the use of miners are given by R. A. S. Redmayne.¹

Mine Surveying.—H. H. Clark² proposes the adoption of electrical symbols for the marking of mine maps, more especially with the object of indicating the lay-out of electric installations in mines.

H. G. Henderson³ deals with some practical points with regard to mine surveying.

W. Pirie⁴ describes various methods of surveying as applied to coal-mining.

J. A. Wentz⁵ deals with the progress made in the prospecting for coal deposits.

Economics of Mining.—A supplement is published⁶ containing the final text of the measure of the new Coal Mines Bill as finally revised by both Houses of Parliament. The Bill is officially described as an Act to consolidate and amend the law relating to coal-mines and certain other mines in the United Kingdom.

History of Coal-Mining.—The early history of coal-mining in Japan is described by K. Nishio.⁷ Coal has been produced in Japan ever since 1702, and the Miike coal-field was first opened in 1721. In the early days coal was chiefly used for domestic purposes, but was sometimes sold as fuel for use in the salt-fields. Coal-mining in early days simply consisted in removing the outcrop. European methods of mining were first introduced at the Takashima colliery in 1867. Literature on mining has existed in Japan from the latter part of the seventeenth century, when Sato Nobukage wrote two treatises on the administration of mines and the principles of the exploitation of mines respectively. He was killed by a gas explosion at the Ani copper mine in Ugo in 1731, a fate somewhat similar to that which overtook his son Nobusuye, who in 1784 was killed by poisonous gases while reopening a tin-mine owned by his father.

Martell⁸ gives an historical account of the coal-mining industry of Belgium. From ancient deeds it appears that coal-mining was being carried on as far back as 1198. Particulars are given of the position of the mining industry at the close of the eighteenth century.

¹ Mines and Quarries, General Report with Statistics for 1910, Part II.—Labour; *Colliery Guardian*, vol. ciii. pp. 77-78.

² *Mining and Engineering World*, vol. xxv. pp. 1329-1331.

³ *Iron and Coal Trades Review*, vol. lxxiv. p. 495.

⁴ Paper read before the Scottish Institute of Mining Students; *Iron and Coal Trades Review*, vol. lxxviii. pp. 721-723.

⁵ *Canadian Mining Journal*, vol. xxxii. pp. 664-667.

⁶ *Iron and Coal Trade Review*, vol. lxxviii. (Supplement), December 15, 1911.

⁷ *Bulletin of the American Institute of Mining Engineers*, 1912, p. 126.

⁸ *Zeitschrift des Zentralverbandes der Bergbau-Betriebsleiter*, November 1, 1911, pp. 455-459.

IX.—COAL WASHING AND SCREENING.

Coal Screening.—P. Sterling¹ describes the preparation of anthracite, and gives a list of the commercial sizes recognised in the American coal trade. The sizing machinery employed consists of screens, which are either fixed or movable. Each of the leading types is fully described and illustrated, and the relative advantages enumerated. Fixed screens are inexpensive as regards first cost, require no power for operation and but little attention, and their capacity is large; but, on the other hand, they effect a poor sizing of the coal, and increased breakage and consequent loss of prepared sizes ensue with their use. The coal is broken either by hand, with picks and bars, or by rolls or crushers, but the first method is employed only in the picking head. Leading types of crushers are described, and estimates are given of the cost of the original installation for the sizing of anthracite and the running charges connected with maintenance.

Coal Washing.—The electrically driven coal-washing plant at Cramlington Colliery is described.² The main plant is driven by a 200 three-phase horse-power motor, and the fine coal recovery-plant and refuse conveyors are operated by two 12 horse-power motors.

The theoretical considerations involved in coal washing are discussed by R. A. Henry,³ who gives curves showing the proportional separation that takes place under actual conditions between the coal and its associated impurities.

G. R. Delameter⁴ puts forward a plea for uniformity in tests and reports of coal washing, and presents some new data and formulæ for accurate comparison of washery work.

D. A. Willey⁵ describes a system of washing bituminous coal at Lahausage, Alabama.

Coal Briquettes.—A. H. Lush⁶ has presented a report to the Home Secretary on the regulations proposed for the manufacture of briquettes with addition of pitch. The processes of manufacture are briefly described, and the risks to health and precautions to be observed are dealt with.

A description is given⁷ of the manufacture of lignite briquettes as carried out at the Verein der Niederlausitzer Braunkohlenwerke, Germany. The lignite is ground into powder which contains about 50 per cent. of moisture. It is then dried and heated by exhaust

¹ *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 749-798.

² *Engineer*, vol. cxvii. p. 648.

³ *Revue Universelle des Mines*, Series IV vol. xxxiv. pp. 68-74.

⁴ *Mines and Minerals*, vol. xxxii. pp. 461-464.

⁵ *Ibid.*, pp. 391-392.

⁶ Board of Trade. Publication Cd. 5878; *Colliery Guardian*, vol. cii. pp. 521-522, 572-573.

⁷ *Dingler's Polytechnisches Journal*, vol. cccxxvi. pp. 737-738.

steam until it contains not more than 12 to 15 per cent. of moisture, when it is passed through a sieve and submitted to a pressure of about 1500 atmospheres, without the use of any binding substance.

Polster¹ describes modern apparatus for the removal of dust, which has been recently installed in the brown-coal briquetting factories of the Rhine district.

An illustrated description is given² of a large double-pressure machine for the manufacture of briquettes from bituminous fuel. The machine is capable of making two 25-lb. briquettes per stroke, and has an output of about 25 tons per hour, equal to some 2200 briquettes.

¹ *Braunkohle*, December 22, 1911, pp. 597-603, 613-621, 645-648.

² *Iron and Coal Trades Review*, vol. lxxxiv, p. 94.

PRODUCTION OF PIG IRON.

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I.—BLAST-FURNACE PRACTICE.

Blast-Furnace Construction.—D. Baker¹ deals with the construction of thin-lined blast-furnaces. In the United States three different forms of construction have been adopted, represented first by the furnace in the Isabella group of the Carnegie Steel Company, Pittsburg, namely, a rolled steel plate shell cooled by water-troughs or pockets riveted to the shell. This furnace is provided with a 12-inch firebrick lining, and there is about an inch of metal between the bricks and the water in the pockets. At South Chicago the shell of the first thin-lined furnace consisted of cast-steel segments bolted together, the cooling being effected by water flowing over the outside surface. A second furnace was built at South Chicago of rolled-plate construction, with water-pockets attached much in the same way as in the Isabella furnace, except that the water, instead of circulating from one pocket to another, is kept in the pocket and allowed to evaporate, enough water being added to take its place. At the plant of the Tennessee Coal, Iron, and Railroad Company, Ensley, Alabama, the thin-lined furnace, recently constructed, has a rolled-steel shell $1\frac{1}{8}$ inch in thickness, which is cooled by water sprays, there being a uniform stream of water flowing down the outside surface of the shell. All these forms of construction differ from the German type, constructed of heavy cast-iron segments, cooled on the exterior, which has proved so successful. The effect of this difference in construction is that the loss of heat in the American furnace considerably exceeds the heat lost in the operation of the German type.

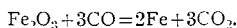
Particulars are given² of the conversion of an ordinary blast-furnace into one of the thin-lined spray-cooled type at the plant of the Detroit Iron and Steel Company.

¹ *Iron Trade Review*, vol. xlix. pp. 1151-1152.

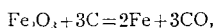
² *Ibid.*, vol. l. pp. 855-857.

Blast-Furnace Reactions.—Zyromski¹ deals with the theory of the blast-furnace reactions, and criticises the views of J. W. Richards communicated to the Düsseldorf Congress. He considers the conditions prevailing (1) in a coke furnace and (2) in a charcoal furnace, and gives formulæ elucidating his contentions. In a charcoal furnace, in order to obtain perfect equilibrium, it would be necessary to heat the blast to 900° C.

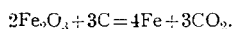
P. Anglès d'Auriac² likewise deals with the theoretical reactions occurring in the blast-furnace, and confirms Gruner's views as to the equilibrium reactions. In the ideal working of a furnace the whole of the carbon in the fuel would reach the level of the tuyeres in an unaltered condition and there be transformed into carbon monoxide, which, rising upwards through the charge, would secure the complete reduction of the ore according to the formula :



This is the ideal instance of indirect reduction. When, however, the reduction of the ore is due to the action of solid carbon, it is to be regarded as direct reduction, and complies with the two formulæ :



and



These two reactions are strongly endothermic, particularly the first one, which absorbs approximately 2400 calories per kilogramme of oxygen withdrawn from the ore. The second, although endothermic, still absorbs nearly 1200 calories per kilogramme of oxygen withdrawn from the ore. In practice the reduction of the ore in a blast-furnace takes place partly at the expense of the carbon monoxide in the ascending gaseous current (indirect reduction), and partly at the expense of the solid fuel descending from the throat (direct reduction). The three reactions given do not however exhaust the exceedingly complex phenomena taking place in the blast-furnace. Thus incomplete reducing reactions occur which yield intermediary oxides instead of metallic iron; and, on the other hand, the reducing action is limited by oxidising reactions, of which an instance is afforded in the oxidising of the reduced iron by the carbon dioxide of the gaseous current, while in the upper part of the furnace the carbon dioxide, in the presence of iron oxides, decomposes into carbon and carbon monoxide with considerable evolution of heat (3134 calories per kilogramme of carbon deposited).

B. Osann³ discusses the reactions obtaining in a blast-furnace under normal working conditions.

M. Levin⁴ discusses theoretically the problems of direct and indirect reduction of ore in the blast-furnace.

¹ *Comptes Rendus de la Société de l'Industrie Minière*, 1911, pp. 574-576.

² *Ibid.*, pp. 576-580.

³ *Stahl und Eisen*, vol. xxxii. pp. 465-473.

⁴ *Ibid.*, pp. 232-234.

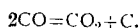
Calculation of Furnace Charges.—R. Chauvenet¹ discusses the calculation of furnace charges, with special reference to the computation of the composition of slags, and gives formulæ and examples for that purpose.

J. J. Porter² points out that the value of any particular ore, coke, or limestone for iron-making depends for its effect, first, upon the quality or value of the resulting product, and, secondly, upon the cost of smelting; and the utility of a means of comparing numerically the relative smelting values of different ores, cokes, and limestones is obvious. A number of empirical formulæ are given, for which simplicity and substantial accuracy are claimed. The formulæ are based on regular sampling and careful analyses, but the benefits of adopting such a course warrant the additional expense entailed.

Blast-furnace Operations.—E. Langheinrich³ draws attention to the fact that the method at present in vogue of removing the molten slag and metal from blast-furnaces in wagons running on rails is unsatisfactory, owing to the fact that the space required might be put to better use and also on account of the high working cost. It is suggested that two systems of overhead travelling-cranes be employed, the one to remove the slag to the waste-heap, the other to carry the molten metal to the mixers. It is recognised, however, that in many works it would now be impossible to introduce this system, owing to the unsuitable nature of the ground and the orientation of the works. It is claimed that if the system is adopted and due precautions observed accidents are almost unknown.

B. W. Head⁴ deals with recent developments in blast-furnace practice.

Deposition of Carbon in the Blast-Furnace.—It is well known that carbon is frequently deposited within the pores of bricks in blast-furnace walls, leading to the splintering of the bricks and their ultimate destruction. This is usually explained on the ground that, at a temperature of 300° to 400° C., carbon monoxide decomposes in the presence of metallic iron or iron oxide, yielding carbon dioxide and free carbon. Thus :



Hence if the bricks contain any particles of iron or iron oxide in their composition, carbon will be deposited in their neighbourhood inside the bricks from the gases diffusing through their pores, resulting in the disruption of the bricks. H. Kinder⁵ points out that this is not the only explanation. The carbon probably also comes in the following manner. Both ore and coke usually contain small quantities

¹ *Metallurgical and Chemical Engineering*, vol. x. pp. 36-39; 104-108.

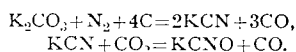
² *Bulletin of the American Institute of Mining Engineers*, 1912, pp. 279-291.

³ *Stahl und Eisen*, vol. xxxi. 1869-1873.

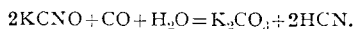
⁴ *Journal of the West of Scotland Iron and Steel Institute*, vol. xix. pp. 267-272.

⁵ *Stahl und Eisen*, vol. xxxii. 231-232.

of the alkali metals as carbonates, and in the furnace these are converted into cyanates. Thus:



In the presence of steam and carbon dioxide, hydrocyanic acid results:



The hydrocyanic acid is now decomposed by particles of iron in the brick into free carbon, hydrogen, and nitrogen.

Charging Appliances.—An electrically operated blast-furnace charging car, suitably designed for use with overhead parabolic ore, coke, and limestone bin systems, is described¹ and illustrated.

Blowing-Engines.—A. Rateau² gives a description of a Rateau mixed turbine and blower installed at a blast-furnace plant in Vizcaya, Spain.

Hot-blast Stoves.—A. N. Diehl³ discusses the relation of regenerative stoves to blast-furnace practice.

G. Bulle⁴ deals mathematically with the working and efficiency of the Cowper stove.

G. H. Smith⁵ describes an expansion joint for hot-blast mains designed by J. Scott.

Mixers.—O. Simmersbach⁶ discusses pig-iron mixers and their application in ironworks. The design and construction of tipping and rotating mixers are illustrated and described, showing the advantages of the rotating type which has now entirely superseded the tipping mixer. The flat-bottom type of mixer is also shown. The operations, the cost of heating, and the influence of the size and the effect of the mixer on the sulphur contents of the pig iron are considered.

A translation into French has appeared⁷ of the paper by O. Simmersbach⁸ discussing the use of pig-iron mixers; diagrams and illustrations of the principal types in vogue being given.

Dry Air-Blast.—A description is given⁹ of an apparatus known as "Little's cooler" for the production of dry air-blast. It consists

¹ *Iron Trade Review*, vol. xlix, p. 832.

² *Zeitschrift des Oesterr. Ingenieur und Architekten Vereines*, vol. lxxx, pp. 625-628.

³ *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xxvii, pp. 662-704.

⁴ *Stahl und Eisen*, vol. xxxi, 1451-1457.

⁵ *Iron Trade Review*, vol. xlix, pp. 1058-1059.

⁶ *Berg- und Huttenmannische Rundschau*, December 20, 1911, pp. 53-60; January 5, 1912, pp. 63-73.

⁷ *Revue de Metallurgie, Mémoires*, vol. vin, pp. 829-850.

⁸ *Stahl und Eisen*, vol. xxxi, pp. 253-268, 337-348, 387-398.

⁹ *Iron and Coal Trades Review*, vol. lxxxiv, pp. 804-805.

of a number of concentric sheet-metal drums, which slowly revolve in a trough, thus producing an extensive surface, each portion of which is covered by a thin film of the liquid contained in the trough. The surface is also necessarily at the temperature of this liquid. The concentric cylinders are arranged in adjacent troughs, and the liquid passes from one to the other (rising in temperature as it does so), in the opposite direction to the air, so that a perfect heat interchange is obtained. Increased thermal efficiency is obtained from this apparatus compared with brine-pipes, as the refrigerating work is divided into two or more stages: (1) The air is chilled by being blown in contact with the concentric drums in the first portion of the cooler, through which water, cooled by the refrigerating machinery, is circulated. (2) The air then passes in contact with the drum surfaces in the second portion of the cooler, through which brine, cooled by the refrigerating machinery, is circulated, and where it is finally cooled to the required temperature. The general arrangement is shown of a plant capable of dealing with 40,000 cubic feet of air per minute and reducing it to a temperature of 25° F., having a moisture content of 1·5 grain per cubic foot.

J. B. Miles¹ describes a new dry-blast process which is in operation at the Northern Iron Company, Standish, United States. The chief feature of this is that the cooling is done after compression in the blowing-engines, and sprays of water or brine in direct contact with the air accomplish the cooling instead of pipes in which cold brine is circulated.

Heym² describes the new calcium chloride plant for drying the blast which has for several months been in successful operation at the Differdingen blast-furnaces. The installation is capable of dealing with 30,000 cubic metres of air per hour.

Enrichment of Blast with Oxygen.—F. W. Lürmann³ raises the interesting question as to whether or not it is advisable to admit more oxygen to the ordinary blast supplied to the blast-furnace than the 21·77 per cent. which the air normally contains. It is pointed out that in the case of a furnace producing 240 tons of pig iron per twenty-four hours, and requiring 40,800 cubic metres of blast per hour, the addition of roughly 1 per cent. of oxygen would raise the temperature in the furnace by some 56° C. This might mean some considerable advantage in cases of emergency, such as scaffolding and irregular working of the furnace. At present, however, the cost of oxygen is rather high, but if it were in greater demand the gas would undoubtedly become cheaper and its advantages more practicable.

Blast-furnace Explosion.—In the early hours of 16th January 1912 a serious blast-furnace explosion occurred at the ironworks of

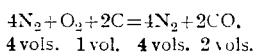
¹ *Iron Trade Review*, vol. 1. pp. 901-904; *Iron and Coal Trades Review*, vol. lxxxiv. pp. 635-636.

² *Oesterreichische Zeitschrift*, vol. lix. pp. 603-605. See also *Journal of the Iron and Steel Institute*, 1911, No. 1., p. 28.

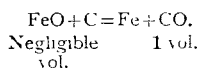
³ *Stahl und Eisen*, vol. xxxii. pp. 609-611.

the Phoenix Company, at Ruhrort, Prussia,¹ resulting in the death of eight men and injury to four others, two of whom have since died. The furnace, which was started on October 16, 1911, was 25 metres in height, and had a capacity of 610 cubic metres. On the night of January 15 the furnace began to work irregularly, and at 1.40 A.M. the explosion took place. It originated evidently just above the boshes, shattering the furnace, but not injuring the Cowper stove close behind.

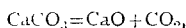
Composition of Blast-furnace Gases.—Experiments have been carried out by M. Levin² and H. Niede upon the composition of blast-furnace gases with a view to throwing light upon the changes taking place during the process of smelting. In order to obtain the gases, holes of 6 centimetres diameter were bored at various heights, vertically above one another, in the walls of certain blast-furnaces, and the gases removed through water-cooled copper tubes. The pressures were registered by a mercury manometer, and the temperatures by a thermo-electric couple. The results are given in a series of curves which show the various proportions of nitrogen, carbon monoxide, and carbon dioxide present in the gases at varying heights above the hearth inside the furnace. The proportion of carbon monoxide rapidly rises as the blast escapes from the tuyere mouth. It then remains fairly constant for some distance at 56.7 volumes per 100 volumes of nitrogen. This constancy persists through half or two-thirds of the way up the furnace, and then the proportion of carbon monoxide slowly falls to 53 volumes at the top of the furnace. The total volume of the furnace gases likewise rises rapidly as the blast leaves the tuyere, but after ascending through about half a metre the rate of increase rapidly falls. The initial increase is largely due to the formation of carbon monoxide both by combustion of the coke in the blast:



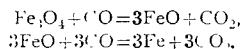
and by the reduction of ferrous oxide by the coke:



As the gases ascend the furnace, carbon dioxide is produced both by decomposition of limestone and at the expense of some of the carbon monoxide. Thus:



and



The former of these reactions occasions a slight increase in the total bulk of the gases, and both reactions reduce the percentage of carbon

¹ *Stahl und Eisen*, vol. xxxii, p. 151.

² *Ibid.*, vol. xxxi, pp. 2135-2140.

monoxide. The carbon dioxide curve thus shows a rapid increase after about one-third of the furnace height has been traversed.

Utilisation of Blast-furnace Gas.—Blast-furnace gas is recommended¹ as superior either to solid fuel or producer-gas for the purpose of drying moulds and the heating of foundry drying-ovens. In view of the fact that refined blast-furnace gas is odourless and extremely narcotising, it is suggested that, in order to reduce the danger attached to its use for drying purposes due to leakages from pipes and burners, it should be mixed with something that will give it an easily noticeable smell. Calcium carbide can be used; the gas in its passage through the pipes being caused to pass over a wire basket containing lumps of carbide, which absorb moisture from the gas and give off acetylene. Means must, however, be provided for shaking the basket periodically in order to free it from accumulations of calcium oxide.

H. Allen² gives some calculations with reference to the utilisation of blast-furnace gas.

M. Langer³ criticises the conclusions of Hoff, that steam-power is cheaper in ironworks than the employment of gas-engines coupled with electric motors.

F. von Holt⁴ also criticises adversely several of the points raised by H. Hoff,⁵ and the latter replies to the criticisms.

A. Gouvy⁶ discusses the economic application of blast-furnace and coke-oven gases in metallurgical works, and shows the saving that can be effected by an efficient installation. The employment of these gases for power purposes in and about the works is exhaustively discussed.

In a discussion on large gas-engines, A. N. Diehl⁷ describes the methods of cleaning and utilising the gas from the blast-furnaces at the Duquesne Steelworks of the Carnegie Steel Company.

Utilisation of Blast-furnace Gases in Open-hearth Furnaces.—R. Buck⁸ deals with the utilisation of blast-furnace gases. Producer-gas has up to the present been employed for the heating of open-hearth furnaces, but is now becoming gradually superseded by coke-oven gas, or rather a combination of blast-furnace gas and coke-oven gas. In order to obtain the high temperature required for the melting of steel, the various gases are mixed in proportions that give a gas with a heating value of from 6400 to 7500 British thermal units. Experiments carried out at the Friedrich-Wilhelmshütte at Mülheim-Ruhr have shown that it is possible to use blast-furnace gas alone, but the process requires considerably more time, and would probably affect the quality of the steel. The coke-oven gas and the

¹ *Engineer*, vol. cxiii. p. 253.

² *Practical Engineer*, vol. xlv. pp. 647-649.

³ *Stahl und Eisen*, vol. xxvi. pp. 2088-2094.

⁴ *Ibid.*, pp. 2007-2013.

⁵ *Ibid.*, pp. 993-1010, 1085-1097, 1130-1142.

⁶ *Bulletin de la Société de l'Industrie Minérale*, Series V. vol. i. pp. 297-326.

⁷ *Journal of the American Society of Mechanical Engineers*, vol. xxxiii. pp. 1079-1089.

⁸ *Stahl und Eisen*, vol. xxxi. pp. 1295-1301.

blast-furnace gas are generally mixed in the proportion of 1 to 4, the mixing taking place before the gases enter the distributing valve. During a period of over two years this combination of gases has been employed at the Friedrich-Wilhelmshütte with very good results for two acid open-hearth furnaces of 12 and 15 tons capacity respectively. At these works the blast-furnace gas passes through a 23½-inch pipe in a rather elevated position. The coke-oven gas, however, passes through a 10-inch pipe underground. The arrangement of the furnaces as regards valves, regenerators, &c., is the same as when producer-gas is employed. Results show that with a mixed gas with a heating value of 6400 to 7600 British thermal units the temperature of the furnace varied from 1700° to 1900° C., according to the proportions of air and gas and the prevailing pressure of the mixed gas. It was impossible to determine the exact proportions of air and gas, but on analysis no excess of air could be discovered. The gases were mixed in proportions varying from 1-3 to 1-6·5, which correspond respectively to 8000 and 6000 British thermal units, and to an average temperature of the furnace of 1800° to 1500° C. For annealing furnaces in steel foundries blast-furnace gas might also be employed. In such cases it is advisable so to arrange the furnaces that the blast-furnace gas mixed with coke-oven gas, or alternatively producer-gas, can be employed as desired.

Blast-furnace Gas Meters.—C. C. Thomas¹ discusses the principles of meters for the measurement of gases in large quantities. The Pitot and the Venturi meters and the author's own electric meter are described, and an account is given of tests with the electric meter.

E. Stach² discusses and gives diagrams of various forms of apparatus designed to register the pressure and velocity of moving gases and vapours. For the former purpose various special types of manometers are explained, whilst for measuring the velocity of the gases either adaptations of anemometers or differential manometers may be employed.

H. Contzen³ gives an account of several forms of apparatus designed to measure the pressure and velocity of motion of gases and vapours.

Cleaning of Blast-furnace Gases.—The "Halberg-Beth" apparatus for the purification of blast-furnace gas is described.⁴ In this system the crude gas enters the plant from the blast-furnace main pipes through an opening into a vertical air-cooler, which has at its lower end a water seal. In this cooler the gas is brought down to a temperature close to its dew point. Leaving the cooler, the gas passes to a receptacle where the temperature necessary for the efficient working of the subsequent filtering operation is obtained and regulated by means of a steam coil. It then passes to the filter apparatus which

¹ *Journal of the Franklin Institute*, vol. clxxii. pp. 411-460.

² *Stahl und Eisen*, vol. xxxi. pp. 1752-1758, 1889-1886.

³ *Ibid.*, vol. xxii. pp. 573-575.

⁴ *Iron and Coal Trades Review*, vol. lxxiv. p. 570.

is installed in a separate compartment, and consists of a number of sections in which linen bags are fastened by their lower and open ends to the floor of the chamber, while the top ends are closed and carried by means of suitable supports. A fan exhausts the gas from the linen bags, whence it passes into the clean-gas main and is conveyed to the Cowper stoves or engines. Further particulars of the "Halberg-Beth" process are given.¹

A method devised by J. Ruddiman of applying the Mullen gas-washer to hot-blast stoves for cleaning the gas is described.²

R. Hamilton³ discusses the removal of dirt from gases of coal-fired blast-furnaces.

Now that the waste gases from the blast-furnaces are washed with water to remove suspended insoluble materials before the gases are utilised for power production, large quantities of dusty water are constantly being produced, and tend to become a source of difficulty to the ironworks. E. Steuer⁴ describes suitable tanks for storing this water, so that the dust particles may settle to a stiff mud and the resulting clear water be used over again.

O. Johannsen⁵ deals with the estimation of dust in flue-gases. Three ways may be employed, namely (1) Passing the gas through water and estimating the amount of suspended material left behind. Apart from the difficulty of manipulation, this method yields uncertain results inasmuch as all the dust is not given up to the water. (2) By passing the gas through asbestos or glass wool. (3) A third method lies in passing the gas through filter paper, and either determining the increase in weight direct, or else converting to ash and determining the weight of the residue.

Briquetting Flue-Dust.—A review⁶ is given of several patents recently taken out in connection with the briquetting of flue-dust.

Asphyxiation by Blast-furnace Gases.—In the course of a report on the cases of asphyxiation by blast-furnace gases that have occurred in Belgium between the years 1906 and 1911, A. Breyre⁷ draws attention to the increase in the number of such accidents of late years. This is ascribed in part to the extending application of the gas as a motive power, so that instead of, as formerly, being consumed in heating the blast-stoves and steam-boilers in the immediate vicinity of the furnaces, the gas has now to be conveyed in mains for some distance and subjected to a secondary purification. Purifying the gas increases its toxic properties, on the one hand, by increasing its density as the result of cooling, and, on the other, by augmenting the proportion of carbon monoxide as the carbon dioxide is dissolved

¹ *Iron and Coal Trades Review*, vol. lxxiv. p. 684.

² *Iron Trade Review*, vol. i. pp. 434-435.

³ *Journal of the West of Scotland Iron and Steel Institute*, vol. xiv. pp. 157-161.

⁴ *Stahl und Eisen*, vol. xxvi. 1759-1763.

⁵ *Ibid.*, vol. xxxii. pp. 16-19.

⁶ *Ibid.*, pp. 264-267.

⁷ *Annales des Mines de Belgique*, vol. xvii. pp. 65-154.

out in the washing water. Apart from this change in composition the gas itself is already dangerous enough, the high percentage of carbon monoxide, as compared with coal-gas, explaining the ease with which fatal asphyxiation can be produced in a very short time, even in the open air. The danger is greatest in the case of the purified gas, for whilst the crude gas contains fumes which reveal its presence and the imminence of danger, the purified gas is invisible and gives no warning of the risk incurred. The author discusses the cleaning out of the gas-mains and pipes, and describes various types of hydraulic seals and valves in use at the different works.

British Blast-Furnaces.—The new furnace recently put into blast at the works of the Barrow Hæmatite Steel Company¹ is 80 feet high, 18 feet 3 inches in diameter at the bosh, and has an 11-foot hearth and 10-foot bell. The body of the furnace is enclosed in a steel-plate casing, and is carried by a built-up ring-box girder supported on ten columns 27 feet long. There are ten tuyeres, the cast-steel housings for which form a complete belt round the furnace. The lower part of the furnace is enclosed in a steel-plate casing, which extends from the bottom of the tuyere housings to about 7 feet below the hearth level. The furnace is provided with four downcomers coupled in pairs. The blast is heated in four Cowper stoves, each 28 feet in diameter and 65 feet high to the springing of the dome. The furnace is blown by five gas-blowing engines, each of 1250 brake-horse-power, which normally furnish blast at a pressure of 12 lbs., but are capable of blowing at 15-lbs. pressure. There is also a set of quarter-crank steam blowing-engines to act in case of emergency. The steam for these engines is taken from a range of eight Babcock boilers, which supply steam to the steelworks, and are fired with blast-furnace gases. The charger consists of an inclined built-up girder, on which runs a counter-balanced travelling bucket-trolley, a transporter-car for travelling the buckets along the line of bunkers, and two buckets for conveying the materials from the bunkers to the furnace.

Russian Charcoal Blast-Furnaces.—M. Jossa² gives an account of charcoal blast-furnaces now being worked in the Urals. It is pointed out that the method of producing the charcoal has an important bearing upon its value. The main details given for three furnaces are condensed into the following table :—

¹ *Iron and Coal Trades Review*, vol lxxxiv. pp. 85-87.

² *Gorní Journal*, 1911, pp. 203-209 ; *Stahl und Eisen*, vol. xxxii. p. 245

Description of Blast-Furnace.	Months of Work.	Iron Yielded.		Charcoal Required.	
		Tons per 24 Hours.	Tons per 100 Tons of Ore.	Volume in Cubic Metres.	Dry Weight in Kilogrammes.
1. At Kuvschinsk—Capacity, 108 cubic metres; height, 17·07 metres; blast pressure, 75 millimetres; blast temperature, 500° C.	January	33·27	57·52	7·157	980
	February	35·22	59·09	6·993	971
	March	35·75	58·19	7·062	901
	April	31·30	57·00	7·888	935
2. At Slatoust—Capacity, 158 cubic metres; height, 17·14 metres; blast pressure, 131 millimetres; blast temperature, 380–400° C.	January	97·95	60·03	4·757	750
	February	100·66	60·90	4·947	770
	March	101·96	60·83	4·727	750
	April	100·53	61·90	4·534	725
3. At Ssatkinsk—Elliptical cross-section—Capacity, 147·8 cubic metres; height, 18·29 metres; blast pressure, 75 millimetres, blast temperature, 445° C.	January	89·15	60·50	4·389	680
	February	101·05	60·10	4·067	667
	March	101·06	60·10	4·146	671
	April	98·86	59·90	4·135	654

Ironworks in India.—C. P. Perin¹ describes the modern progress of the iron and steel industries in India, with special reference to the plant of the Tata Iron and Steel Company. Exploratory work was commenced in 1903, and resulted in the development at Gurumaishini, 44 miles from the steel plant, of a very large ore body running high in iron. The width of the vein at Rajara Hill is 180 feet, where the ore shows 67 per cent. of iron, with 0·06 to 0·08 per cent. in phosphorus. Eighteen well-defined coal-seams have been found in the Jherria field, ranging from 5 to 32 feet in thickness. The coal-mines are about 100 miles from the steel plant, and the dolomite and limestone quarries about 120 miles. The Tata Iron and Steel Company's plant is at Sakchi, near the town of Kalimati, which is 152 miles west of Calcutta. There are two blast-furnaces, a 300-ton mixer, four 40-ton open-hearth furnaces, and rail, beam and bar mills; also 180 coke ovens of the Coppée non-recovery type. It was decided that it would be impracticable to attempt by-product recovery, in view of the impossibility of condensing ammonia with water at temperatures ranging from 98° to 110°. The volatile content of the coal ranges from 19 to 28 per cent., and its average ash is about 18 per cent. It produces a hard, strong coke.

Chinese Blast-Furnaces.—Cho-Yang² and Chang-Fu Wang give some notes on the Han-Yeh-Ping Iron and Coal Company, China, whose operations are carried on at three chief plants: (1) Hanyang

¹ Paper read before the New York Section of the American Institute of Mining Engineers; *Iron Age*, vol. lxxviii, p. 682.

² *School of Mines Quarterly*, vol. xxxiii pp. 165–171

iron and steel works; (2) Ta-yeh iron-mines and limestone quarry; and (3) Ping-hsiang coal-mine and coking plant.

American Blast-Furnaces.—The two new modern blast-furnaces under erection for the Minnesota Steel Company are described.¹ The stoves are of the three-pass type, 22 feet 6 inches in diameter, 100 feet high. The furnaces will be 21 feet 6 inches in the bosh, the shells being lined to a thickness of only 12 inches. One of the novel features of the furnaces will be the dry-cleaning devices for eliminating dust from the gas. From the top of each furnace there will be four uptakes, each leading into a centrifugal dry-gas cleaner, the downcomer pipe being taken off from the latter and discharged into another set of centrifugals at the bottom of the furnaces. These centrifugals again discharge into two others of larger size, from which the gas is distributed to the various places for use, some passing through Zschocke washers and some going direct to stoves and boilers. The Neeland charging equipment will consist of a single skip with bottom-discharge bucket. The furnaces will be water-cooled from top to bottom, the boshes being fitted with copper cooling-plates, and the shells with outside troughs clear to the top.

Details are given² of the blast-furnace plant of the Western Steel Corporation. These works, which are the only ones west of the Rocky Mountains, are situated at Irondale, Washington. The blast-furnace is 56 feet high, 11 feet in diameter at the bosh, and 6 feet at the crucible. The blast is furnished by two vertical Wymer blowing-engines, which are used alternately. The temperature of the blast is limited to about 900° F. The furnace is charged by hand, the ore being carried to the top by elevators. The ore bunkers have a capacity of 1500 tons. The blast-furnace has a daily capacity of 70 tons, and was rebuilt in 1909.

A description is given³ of the new blast-furnace recently added to the Haselton plant of the Republic Iron and Steel Company. The furnace has a bosh diameter of 22 feet, is 16 feet in diameter at the top, and is 90 feet high. It has a daily capacity of 500 tons.

The two new blast-furnaces recently erected at the plant of the Rogers-Brown Iron Company, Buffalo, are described⁴ and illustrated. Both furnaces are 85 feet in height, and are equipped with 12 tuyeres. Each furnace is served with four Kennedy central combustion, two-pass stoves, 22 feet in diameter and 102 feet high. The three Tod blowing-engines are of the horizontal cross-compound type, with air cylinders placed in tandem with the steam cylinders. The engines are designed to blow against a normal air-pressure of 18 lbs. and a maximum pressure of 30 lbs. The blast-furnaces have a daily capacity of approximately 350 tons each.

¹ *Iron Age*, vol. lxxxviii, p. 331.

² *Iron Trade Review*, vol. xlix, pp. 1003-1008.

³ *Ibid.*, pp. 1135-1138.

⁴ *Ibid.*, vol. l, pp. 797-803.

Australian Iron Industry.—F. W. Paul,¹ who was invited by the Government of New South Wales to visit the State and report on its iron and steel industry, states that, both as regards quantity and quality, the ore in New South Wales combined with that of the other States warrants the expenditure of the necessary capital outlay for the equipment of blast-furnaces and iron and steel works for manufacturing the whole of the iron and steel requirements of the Commonwealth. He also considers that the supplies of coal and coke will be adequate for the same purpose when the necessary development takes place. The author states that, given a modern blast-furnace plant producing, say, 5000 tons of pig iron per week, part of the output of which would be used in connection with a steel plant, pig iron, comparing very favourably with English hæmatite iron, could be produced at 54s. per ton, being 7s. per ton lower than is found in good practice in England.

Charcoal Iron Process.—Particulars are given² of a new process for the manufacture of charcoal iron devised by J. J. Hudson, which is in operation at the works of the Vulcan Charcoal Iron and Steel Company, Crum Lynne, Philadelphia. This consists in melting the charge between layers of charcoal in a specially designed furnace of the open-hearth type. The furnace is preheated by oil or gas, and a thick layer of charcoal is then introduced, on which the charge is placed and melted by the aid of cold air-blast. After the charge is melted it boils and filters through the charcoal which eliminates the impurities from the molten mass. Different types of furnaces may be employed for the process, a 15-ton furnace being used at present. The character of the charge is regulated by the quality of the product to be produced, but in all cases both charcoal and flux are used to increase the heat and continue the refining. Sulphur, phosphorus, silicon, and other impurities can be reduced to a minimum, it is claimed; the mass being decarburised until the analysis of the molten metal shows the quality of iron required. The charge usually consists of pig iron, wrought iron, or steel scrap.

Chemical analyses of eight heats show:

Carbon.	Manganese.	Silicon.	Sulphur.	Phosphorus.
Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
0.04	0.05	0.016	0.024	0.022
0.035	0.08	0.026	0.035	0.028
0.03	0.07	0.023	0.034	0.034
0.03	0.06	0.019	0.032	0.014
0.025	0.06	0.053	0.032	0.016
0.03	0.05	0.016	0.039	0.028
0.04	0.07	0.021	0.024	0.024
0.04	0.11	0.017	0.030	0.022

¹ *Engineer*, vol. cxiii. pp. 245-246.

² *Iron Trade Review*, vol. I. p. 951.

Physical tests of one of these heats gave the following results :

Elastic Limit Pounds per Square Inch.	Tensile Strength Pounds per Square Inch	Elongation 8 Inches per Cent.	Reduction of Area per Cent
27,700	43,200	27.25	69.6
29,600	45,000	25.5	75

Electric Smelting of Iron Ore.—O. Frick¹ discusses the results obtained in the electric furnace at Trollhättan, Sweden. He concludes that the results prove that the electric reduction of iron ore can be carried out in a technically satisfactory way, although the process is open to improvements by which the cost of production can be reduced. By eliminating the water from the circulating gas, the coal consumption can be reduced by about 14 per cent., and the use of burnt lime instead of limestone will secure a further economy as there will be less carbon dioxide in the gas, which will thereby become more strongly reducing. Other considerations lead to the belief that further economies can be effected. Tables are given showing analyses of the raw materials, gases and slag, and the amounts of raw materials employed per ton of pig iron, together with appendices showing the coal and power consumption during various periods.

J. A. Leffler² criticises some of the statements made by O. Frick in regard to electric reduction of iron ores at Trollhättan.

J. J. Smith³ controverts the assertion that the white appearance of the blowholes which occur in a low-silicon, low-carbon pig iron produced in the electric furnace is due to the entire absence of an oxidising condition and of oxides in the hearth of the electric furnace, and points out that he has made white iron full of similar blowholes in a charcoal blast-furnace. These blowholes are produced by the action of the imperfectly reduced ore in the bath reacting on the carbon (presumably that dissolved in the iron) and thereby forming carbon monoxide. The electric furnace will come into its own in time, but the growth should be a natural one, unhindered by extravagant claims which sometimes tend to excite ridicule.

T. D. Robertson⁴ deals with the working of the electric shaft-furnace for smelting iron erected at Trollhättan, Sweden.

J. B. C. Kershaw⁵ reviews recent developments in the electric smelting of iron ore, and describes the various furnaces in use, including the Stassano, Keller, Heroult, and Grünwall types.

P. Nicou⁶ gives an account of experiments carried out at Trollhättan

¹ *Metallurgical and Chemical Engineering*, vol. ix pp. 631-639.

² *Ibid.*, vol. x. p. 71.

³ *Ibid.*, vol. ix. pp. 624-625.

⁴ Paper read before the American Electro-Chemical Society; *Mechanical Engineer*, vol. xxviii. pp. 815-817.

⁵ *Iron Trade Review*, vol. 1. pp. 41-46.

⁶ *Revue de Métallurgie, Mémoires*, vol. ix. pp. 209-252; *Revue Universelle des Mines*, Series IV. vol. xxxvii. pp. 127-184.

from November 16, 1910, to May 29, 1911, with numerous tables showing the working of the furnaces, estimates of the cost, analyses of the materials employed and of the charges, the pig iron produced, the slags and the gases. The results were highly favourable to the process employed, and showed that pig iron may profitably be obtained in Sweden by the electric process as compared with the ordinary conditions of charcoal smelting.

Native Methods of Iron Manufacture.—Notes are given¹ of the native methods of obtaining and working iron in North-west Cameroon. The blast-furnace is built of clay, and is fitted with four tuyeres. Bog ore, charcoal, and wood are charged into the furnace, and the molten metal runs into a hollow below.

History of Iron.—O. Johannsen² draws attention to the tract written by the Florence architect, Antonio Averlino, under the name of Filarete, between the years 1460-1464. In this tract is given a graphic account of the methods adopted for extracting iron from its ore. The fuel and ore were thrown in at the top of a stone furnace, and a blast supplied by powerful bellows of oxhide worked by water-power. Two such bellows were attached to each furnace, but only one nozzle or tuyere. The molten iron collected just below the tuyere, and, when sufficient had been produced, a fresh hole was made immediately below the tuyere and molten metal allowed to flow out into a trench filled with water. If a casting was required in this metal it was only necessary to place a mould between the furnace and the trench, and the metal on its way to the latter would fill the mould, the excess collecting in the trench. The casting was removed when cold, heated and melted in other furnaces, and worked with a hammer into the desired form. The existence of this tract shows that even in the fifteenth century cast iron was valued and produced on a relatively large scale.

J. Lewis³ in a lecture before the Association of Men of Sussex describes the early manufacture of iron in Sussex. The earliest period recorded in connection with the industry, according to the author, was from 1233 to 1244, during which time Bishop Finch, then of Chichester, was ordering ironwork for Winchester Cathedral, but undoubtedly much earlier than that the material had been mined and worked. Probably as far back as 500 B.C. the Britons would have learnt something of the value of iron from their Continental neighbours, who were using it to a limited extent, but with the exception of a figure about which much discussion had arisen there was no finished article of pre-Roman or even Roman times. Caesar's first occupation was brief, and it was not until their second coming that the Romans seriously attempted to revive, or possibly create, the Sussex iron industry. Practically nothing was known about this phase of iron-making in the southern counties until 1844, when excavating opera-

¹ *Stahl und Eisen*, vol. xxxi. p. 1477.

² *Ibid.*, pp. 1960-1963.

³ *Ironmonger*, vol. cxxxviii. p. 447.

tions proved, from articles found, that at Maresfield there had been important ironworks covering an area of about seven acres. This discovery led to investigations in other parts of the country, and, among other places, similar remains were found at Bathurst, Chiddingly, and Seddlescombe. It is significant that in Domesday there was no reference at all to the Sussex iron industry. The Normans, however, appear to have reopened the workings, but it was not until 1266 that Henry III. granted a charter to the citizens of Lewes, whereby they were allowed to levy toll on all iron brought into the town. There are further records, dated 1290, showing that ironwork was supplied for Westminster Abbey. The earliest reference to cannon was in 1301, when they were made at Amberley. The earliest tilt-hammer was in all probability a counterbalanced tool, upon the free-end of which the workman stepped in order to raise it for the blow. There is unfortunately no proof to show when the problem of the blast was first met effectively. Undoubtedly bellows were used, first single and then double, and these were also operated by water-wheels. In due course, however, the casting of cannon grew to considerable proportions, and there is one known transaction entered into in the sixteenth century for the Duke of Cumberland for the supply of forty cannon of 3 tons weight each. With regard to the hammers the author refers to a remarkable striker which was found in India about 1864 when the railway was being built between Allahabad and Jubbulpore. While digging for ballast the contractors came upon coins and some pottery, and near by was found a hammer-head which was curiously like the tool which subsequently became familiar to the Sussex ironworkers. Approximately it was 24 inches long, 15 inches wide, and 9 inches thick, and roughly heart-shaped; the upper part was pinched in, presumably to provide shoulders for the beam.

In dealing with Belgian metallurgy Baron de Lavelaye¹ states that Godefroid Box, of Liège, built the first foundry in England at Dartford in 1580. The manufacture of pocket-knives was also introduced into Sheffield in 1650 by a Belgian workman from the Walloon district. These knives are still known as "Joctelegs," a corruption of Jacques de Liège. When gun-barrels were first made by Ralph Hogg in his ironworks in Sussex in 1543 he employed a Belgian gunsmith, Pierre van Collet, to make the ammunition.

E. Jagsch² gives an account of the early blast-furnace practice in Upper Silesia. At one time the country possessed almost inexhaustible quantities of wood, so that the early blast-furnaces were worked with charcoal. In 1789 an attempt was made to employ a mixture of coke and charcoal, and two years later peat and charcoal were tried together. Neither of these experiments proved very successful. At the beginning of the nineteenth century several blast-furnaces were worked entirely with coke, but owing to the employment of poor coke

¹ *Engineer*, vol. cxviii, p. 353.

² *Stahl und Eisen*, vol. xxxi, pp. 1525-1534.

and too weak a blast several years elapsed before the industry showed signs of serious improvement. In 1850 Upper Silesia possessed no fewer than sixty-six charcoal and thirty coke blast-furnaces.

Mathesius¹ gives an historical account of the development of the German iron industry since the introduction of the basic Bessemer process. Statistics of production are quoted, and the technical improvements in methods of production and manufacture are mentioned.

The history of the metallurgy of iron in Japan is described by K. Nishio.² Iron was formerly smelted from the magnetic sand in the regions of Idzumo, Iwami, Bitchū, Bingo, and Aki. In the valley of the Tojō river there were no fewer than 267 places worked for magnetic sand in 1671. At the beginning of the eighteenth century the metallurgy of iron received an impetus from the invention of balance-bellows, which superseded the old tread-bellows formerly used which required eight men to operate. Shaft-furnaces were built in 1855 at Kobui, Oshima, and Hokkaido. The Kamaishi iron-mine was discovered in 1823. Smelting was commenced in 1849, and in 1860 shaft-furnaces were built to smelt the ores.

II.—BLAST-FURNACE SLAGS.

Composition and Uses of Blast-furnace Slag.—H. Fleissner³ discusses the properties and uses of blast-furnace slag. The results of melting-tests of slags of various compositions are given.

Utilisation of Waste Heat of Slags.—Particulars are given⁴ of an experimental plant for the utilisation of waste heat from blast-furnace slags. In the plant described which is installed at the iron-works of Sir B. Samuelson & Co., Limited, Middlesbrough, practically the whole of the heat in the slag is effectively imparted to the water in the boiler, the steam generated being used in a low-pressure turbine. The system is based on the Vautin patent. Chemical analyses have shown that no trace of sulphuric acid can be detected in the steam when condensed; that the amount of sulphuretted hydrogen is not sufficient to be harmful to the blades of a turbine; that the steam, though almost instantaneously generated, is superheated about 70° F.; and that the quantity of steam generated from a furnace producing 1800 tons of slag per week could safely be relied upon to develop 500 kilowatts of electric current per hour with an expenditure of 6 horsepower for operating the plant. The following figures may be taken as representative of the quantities of the principal constituents in a large number of samples of granulated slag and condensed steam analysed from time to time.

¹ *Verhandlungen des Vereines zur Beforderung des Gewerbflusses*, January 1912, pp. 35-76.

² *Bulletin of the American Institute of Mining Engineers*, 1912, p. 125.

³ *Oesterreichische Zeitschrift*, vol. ix, pp. 29-34, 46-49.

⁴ *Iron and Coal Trades Review*, vol. lxxiv, p. 607.

Slag—silica, 28·5 per cent.; alumina, 19 per cent.; lime, 36·4 per cent.; sulphur, 1·12 per cent.; iron, from 0·7 to 2·5 per cent. Steam (in grains per gallon)—chlorine, 0·4; total sulphur, 10; sulphuretted hydrogen, 3; acid, 0.

The corrosion of the shell of the boiler, after alternately working and being exposed to atmospheric influences for several months, is quite normal and uniform, showing no sign of pitting. A quantity of clean mild-steel drillings was placed in a sample of the condensed steam, and at the end of a fortnight the water was drained off and found to contain no trace of iron.

Crushing Slag.—C. Abels¹ gives a description of a plant for the crushing of blast-furnace slag which has been erected in Stieringen. The blocks of slag from the bogies are allowed to cool, and then broken by hand with hammers to pieces not exceeding 25 centimetres in diameter. These pieces are taken by trolleys attached by an endless chain to the breaking-house, where they are crushed and sieved.

Slag Cement.—H. Passow² draws attention to the value of iron Portland cement for constructional engineering purposes.

H. Fleissner³ discusses the utilisation of blast-furnace slag, and gives an account of several different methods for preparing cements therefrom.

¹ *Stahl und Eisen*, vol. xxxii, pp. 614-617.

² *Ibid.*, pp 477-480. ³ *Ibid.*, pp 224-231.

FOUNDRY PRACTICE.

Cupola Construction.—M. Albuetz¹ discusses the construction of cupola linings and the material of which they are composed, together with the relation of fluxes and slag thereto. The cause of the rapid destruction of the lining is also dealt with.

W. J. May² in dealing with the repairing of melting furnaces indicates the method of construction of linings which facilitates such work.

Portable Cupola for Emergency Work.—H. M. Lane³ describes the construction and operation of a small cupola, of a portable type for emergency work when it becomes necessary to effect immediate repairs to mining machinery. The cupola can be used either with anthracite coal or with coke, provided the sulphur is not too high. The special conditions which require to be observed in working a small portable cupola of this nature are described in detail. Such a cupola can be used for a variety of purposes, and is a valuable adjunct in railway work.

He also describes⁴ foundry operations generally, with special reference to the repairing of mining machinery.

Cupola Practice.—A new form of combined cupola and air-furnace, known as the Holland cupola, is described and illustrated.⁵ A vertical cupola is charged in the usual way, and the iron may be drawn from the cupola in part, leaving the remainder to flow into the reverberatory or air-furnace. Oil fuel is used in the latter, and a close degree of control may be had over the oil-burning flame in the heating and purification of molten metal in the reverberatory. Into the molten mass in the reverberatory furnace the finely divided particles of metal, such as filings, borings, and turnings, are added. If it were attempted to utilise them in the vertical cupola, the metal granules would be carried away by the blast or to a large extent quickly oxidised. The heated gases from the reverberatory are conducted to the cupola, so that a maximum utilisation of the heat generated is accomplished with a resultant increase in melting

¹ *Foundry Trade Journal*, vol. xiii. pp. 590-595, 704-707.

² *Ibid.*, pp. 726-727.

³ *Engineering and Mining Journal*, vol. xcii. pp. 804-808.

⁴ *Ibid.*, pp. 847-851, 894-896, 938-940.

⁵ *Iron Age*, vol. lxxxviii. p. 644.

capacity, as a plant in Brooklyn has shown. The slag from the cupola passes into the reverberatory on top of the molten iron. When all the metal from the cupola is drawn through the reverberatory furnace, a higher-grade product is obtainable than would otherwise be the case. Arrangements can be made for using other forms of fuel than oil for the reverberatory furnace, and the blast can be preheated slightly.

E. Leber¹ gives an account of the progress obtained in foundry practice during the last ten years.

In his presidential address to the Sheffield Branch of the British Foundrymen's Association, P. Longmuir² deals with the development of iron and steel founding.

An account is given³ of German and other iron and steel foundry practice.

Foundry Mixtures.—A. W. Whitney,⁴ in dealing with the control of mixtures for cast-iron car-wheels, discusses the advantages of the microscope in car-wheel practice, and gives some remarkable examples of cast-iron chills.

Use of Scrap-iron Briquettes in the Cupola.—It is customary to briquette cast-iron drillings before using them in cupola practice. H. Adámmer,⁵ however, points out that the drillings may be utilised direct in the cupola with advantage. He claims that the loss incurred is considerably less than that given by Messerschmitt,⁶ provided suitable proportions of the cast-iron scrap are employed.

Recovery of Iron from Foundry Waste.—G. Rietkötter⁷ draws attention to the enormous quantities of good iron thrown away in foundry slag-heaps. It is not an uncommon thing in Germany for the waste slag from cupola furnaces to contain as much as 12 per cent. of its weight of metallic iron. This is mostly present as small pellets firmly fixed in and scattered throughout the mass of the slag. Even in the most economical cases the quantity of iron amounts to 4 or 6 per cent. When one considers the vast quantities of cupola slag produced throughout the civilised world, the loss of iron thereby entailed is tremendous. The author points out that several firms in Germany now crush their cupola slag in order to liberate the fragments of iron, and subject the whole to magnetic separation. Several adaptations of the well-known revolving-drum electro-magnetic separators are described and illustrated, as being particularly suitable for the purpose in view.

In view of the notable tendency at the present time to recover iron

¹ *Stahl und Eisen*, vol. xxxii. pp. 526-533.

² *Foundry Trade Journal*, vol. xiv. pp. 104-107.

³ *Stahl und Eisen*, vol. xxxi. pp. 1957-1960.

⁴ *Iron Trade Review*, vol. i. pp. 559-602.

⁵ *Stahl und Eisen*, vol. xxxi. pp. 1799-1800.

⁶ *Ibid.*, vol. xxx. pp. 2064-2071.

⁷ *Ibid.*, vol. xxxi. pp. 1790-1792.

from waste products in ironworks, foundries, and blast-furnace plants, G. Freimut¹ gives an illustrated description of the Rietkotter-Kuhn apparatus designed for the purpose of separating iron from rubbish in the foundry. The apparatus comprises a system of stationary magnets formed of two pole-cores, each composed of a bundle of mild-steel plates, surrounded by copper coils arranged to give opposite polarity. The whole is mounted on a shaft firmly secured at two points. The individual plates of the pole-cores are bent in the form of a secant towards the cylinder casing, thus ensuring uniform distribution of the magnetism over the zone destined for the separating process. The casing which rotates about the magnet system is made of powerful iron bars of zig-zag shape, engaging in one another, and secured to a gun-metal hub rotating on the shaft. In passing by the magnet system the bars of the casing are converted into secondary poles, which retain the iron until it has been carried out of the sphere of influence of the lines of magnetic force. The conductors for the electric current are led through the hollow shaft in order to avoid the use of contacts and brushes, which are undesirable in foundry work. As the cylinder bars pass by the magnet system a continuous inversion of polarity occurs, with the result that the iron retained on the casing is maintained in constant motion, so that it is well freed from sand, and is recovered as a pure iron product. Since the lines of force generated by the electric current run in the same direction as the material to be transported they are able to act to the best advantage, and all losses by dispersion are prevented by the use of suitable precautions. Particulars of a plant installed at the Gelsenkirchner Bergwerk, A. G., Rothe Erde, Aix-la-Chapelle, are given, together with figures showing the return from such a plant installed for treating a spoil-heap and dealing with 10 tons of material per hour.

Foundry Equipment.—A description is given² of a 30-ton travelling-crane with a revolving jib, which can be turned and guided underneath and between the crane-track girders in such a manner as to serve the entire floor of a foundry and permit of castings being taken from one part of the shop to another. Two such cranes of 30 tons lifting capacity, and two of 15 tons, have been installed at the works of Thyssen & Co., Mulheim-on-Ruhr.

An illustrated description is given³ of a new overhead foundry crane installed at the works of Thyssen & Co., of Mülheim-on-Ruhr.

An illustrated description is given⁴ of a jacketed foundry ladle designed for keeping accumulated molten metal at the same temperature as when it leaves the cupola, in cases where the latter is not sufficiently large to melt in one heat the whole of the metal required for a casting. The ladle, which is made of cast steel, is surrounded

¹ *Foundry Trade Journal*, vol. xii. pp. 577-580.

² *Ibid.*, pp. 732-733.

³ *Iron and Coal Trades Review*, vol. lxxxiii. p. 855.

⁴ *Foundry Trade Journal*, vol. xiv. pp. 166-167.

up to the level of the trunnions with a jacket, thus leaving a space of from 1 to 2 inches. Into this space a sufficient supply of hot gases is introduced, the latter being obtained from the waste gases of the cupola or from some type of mould drier. The hollow space extends over the whole area of the ladle bottom. The temperature of the gases is from 400° to 500° F., and the accumulation can, therefore, extend over several hours without the metal being affected by chill.

In view of an accident that occurred owing to the inefficiency of the catch of a foundry ladle that was intended to prevent its accidental overturning, a safety device was substituted, of which an illustrated description is given.¹ On the squared trunnion of the ladle a bar of about 1 foot long was shrunk and pinned. When the ladle was in a vertical position one end of this bar rested on an adjustable screw, and beneath the other end of the bar was a catch, pivoted on a pin, having sufficient potential movement to enable it to clear easily the end of the bar. By means of this device, the action of which is described, the ladle, in its vertical position, is locked so that it cannot move when being filled or removed from one place to another, neither can it rock. The apparatus is adjustable to the wear of the trunnions and other parts, and does not interfere with the handling of the ladle by the crane.

An illustrated description is given² of the mechanical handling arrangements in the annealing department of a malleable iron foundry producing bulky work in large quantities.

H. S. Green³ in dealing with modern foundry equipment describes and illustrates various machines and appliances that are employed in present-day foundry practice.

Oil-fired Open-hearth Furnaces for Steel Foundries.—The equipment of the steel foundry of the National Brake and Electric Company, Milwaukee, is described⁴ and illustrated. This includes two acid open-hearth furnaces, one of 15 tons capacity and the other 5 tons. The large furnace is of the Campbell tilting type, and uses crude oil for fuel. The oil is pumped to the furnaces under a pressure of 60 lbs. per square inch. Two burners are provided, one for each end of the furnace, and are used alternately. The burners are exceedingly simple. There are two upright pipes, each provided with a regulating valve. One pipe carries oil, and the other air under a pressure of 80 lbs. per square inch. The oil and air pipes are joined at the top by double elbows, which act as trunnions and terminate in a single long burner. About four hours are required to melt a 12-ton heat. Only two heats a day are tapped from the furnace. Sufficient oil is burned in the night to keep the furnace warm enough to avoid excessive expansion and contraction.

¹ *Foundry Trade Journal*, vol. xiii. pp. 728-729.

² *Castings*, vol. ix. pp. 60-61.

³ Paper read before the Halifax Branch of the British Foundrymen's Association, December 16, 1911; *Foundry Trade Journal*, vol. xiv. pp. 90-93.

⁴ *Iron Trade Review*, vol. xlix. pp. 911-920.

A description is given¹ of the arrangement and equipment of the new steel-casting plant erected by the Union Steel-Casting Company, Pittsburg. The melting equipment consists of two 25-ton acid open-hearth furnaces, designed to burn either producer-gas or oil as fuel.

E. Richarme² gives dimensional drawings and illustrations of an oil-fired open-hearth furnace employed at the Tsaritsyne Works, Russia, for the production of steel castings and special steel. The furnace is heated with residues derived from the distillation of naphtha. There are two air-chambers, and the hearth is composed of a double layer of magnesia bricks. The hearth is covered with a false bottom of granular magnesia mixed with 25 per cent. of slag and rammed hot, while the back wall and the ports are built of magnesia bricks, with the exception of the upper portions, which are faced with silica brick, and the roof is made up of silica bricks. The furnace ran from April 23, 1907, to November 17 in that year, and made 1129 charges before it was necessary to shut down, only eight days being required for repairs, and the succeeding run comprised 1694 charges. By this time the roof was in bad condition, and advantage was taken in making repairs to alter the curve of the arch and to introduce further modifications. The cost of the installation and the cost of making steel are given in tabular form. The capacity of the furnace is from 4 to 4½ tons per charge, and the number of charges obtained per twenty-four hours averages 5·7, taking the figures given for the first run; for the second run was carried out under more favourable circumstances, and it was possible to obtain six charges per twenty-four hours, and sometimes even seven. The oil residue or mazout, as it is commonly called, has an average density of 0·91 at 15°. It ignites at 70°, and has a calorific value of 11,200 calories. A special injector is employed for feeding the fuel, which is pulverised during injection by compressed air. The Tsaritsyne Works possess seven other 20-ton open-hearth furnaces, and the whole of the material is charged cold. They make on an average three charges a day each, and under certain conditions four charges can be obtained.

Converters for Steel Foundries.—Details are given³ of the working of a small Bessemer plant for steel castings, together with figures relating to cost of production as obtained from German practice. The small converter may also be employed for making cast iron of high breaking strength. The method consists in mixing white iron that has been blown to a high temperature in the converter with molten pig, the resulting metal possessing, in consequence of the chemical reaction, a temperature that is unattainable by any kind of cast iron. The high temperature of production of this special grey iron—the characteristic composition of which is 2–3 per cent. of carbon, 1–2 per cent. of silicon, and less than 0·5 per cent. of manganese—also gives it excellent physical properties. The cost of

¹ *Iron Trade Review*, vol. I. pp. 99–108.

² *Revue de Métallurgie, Mémoires*, vol. viii. pp. 882–890.

³ *Foundry Trade Journal*, vol. xiii. pp. 700–703.

production is about £1 per ton more than that of good cupola iron. Illustrations of possible methods of arranging a small converter plant are given.

Oil-fired Converters for Foundries.—W. Stock¹ describes his oil-fired converter process for the manufacture of steel.

An illustrated description of the Stock process for the production of steel castings, as recently installed at works in Darlington, Sheffield, and elsewhere, has appeared.² The process involves the use of a new type of small Bessemer converter, and the converter installed by the Darlington Forge Company at their works is one of 3 tons capacity. One of the features of the process is that the cupola is dispensed with; the melting of the metal previous to blowing being accomplished in the converter itself, crude oil being used as fuel. The vessel is of oval section, so as to expose the largest possible surface of the metal to the action of the oil burners, and the tuyere box was designed for the most effective action of the blast and of the oil jets. The converter is lined with silica brick running up to a thickness of 13 inches around the tuyeres. For convenience of working, in addition to the mounting on trunnions working in roller-bearings, a turntable is provided for the revolution of the vessel. Three tons of pig iron and scrap can be charged by three men in about ten minutes. After charging, the vessel is moved through an angle of 90° into the position for melting. Here the nose of the converter is pointed toward the air-heater or economiser. The hot gases from the burning oil are drawn through the heater by means of the chimney-stack. Blast is supplied in the case of the 3-ton converter by a Roots pressure-blower with a capacity of 3000 cubic feet per minute, the blowing pressure varying from $\frac{3}{4}$ lb. per square inch for melting to $3\frac{1}{2}$ lbs. per square inch as the maximum for converting. Air from the blower is delivered into the heater through the inlet pipe shown, and after passing through the system of pipes goes to the converter. In melting, the air which passes through the tuyere enters the vessel at a temperature of about 800° F., and in the burning of the oil a very close approach to perfect combustion has been secured. With a 3-ton converter the metal is melted in about $1\frac{1}{2}$ hours. The blow which follows takes from 15 to 25 minutes. Thus a blow every two hours can ordinarily be made. The oil used for melting is forced by the blower or by an air-compressor into a smaller tank which contains a sufficient quantity for five to six meltings. This service tank is fitted with a coil through which hot air or steam can circulate so as to decrease the viscosity of the oil. With liquid fuel for melting there is no taking up of impurities in this process. The high temperature of the melted charge permits of using pig iron low in silicon as well as high percentages of scrap, and a very fluid steel is secured, making it possible to obtain difficult and intricate castings.

¹ Paper read before the Sheffield Branch of the British Foundrymen's Association; *Iron and Coal Trades Review*, vol. lxxxiv. p. 643.

² *Iron Age*, vol. lxxxviii, pp. 524-526.

F. C. Perkins¹ also describes the oil-fired converter that is in use at the works of the Darlington Forge Company, Limited, Darlington.

Pressure of Liquid Iron on the Mould.—In dealing with the pressure of liquid iron on the mould, it is stated² that long castings should always be poured in a vertical position in order to obtain the fullest advantage of the ferrostatic pressure which drives the specifically lighter slags, gas, air, steam, and sand that are present in the mould upwards, so that the casting becomes clean and dense. The pressure of the iron in kilogrammes per square centimetre of the mould wall is given by the expression :—

$$0.1 \times \text{height of metal (metres)} \times \text{specific gravity of metal (7.25)}.$$

Therefore, for a pipe 6 metres (20 feet) long, there would be a pressure upon the bottom walls of the mould equal to 0.1 by 6 by 7.25, equal to 4.35 kilogrammes to the square centimetre (61.77 lbs. to the square inch), or 4.35 atmospheres. The larger the area of the casting, and consequently the liquid iron, the greater is the upward pressure and the rise of the iron. An iron plate 3.3 feet square poured from a height of 10.8 inches sustains a pressure of 3.08 lbs. to the square inch, the pressure working upward being equal to 4875 lbs., thus showing the need for care in constructing the moulding-boxes.

Foundry Patterns and Moulding.—In view of the trouble experienced in making thin castings of large area on account of warping, and that unequal cooling in different parts of the casting may cause it to twist or warp so badly that it may become worthless, H. E. Thompson³ has designed a moulding-flask, by the use of which it is claimed the troubles incident to such castings can be overcome. The flask is equipped with a number of straddling abutments resembling small jack-screws, which are clamped to the flask bars, both in cope and drag, and screwed down to such a position as to bear against the casting and hold it in shape while cooling.

C. T. Schaefer⁴ describes and illustrates a method of making a pattern for and moulding a double-cylinder casting for automobile and aeronautical engines.

At a meeting of the Lancashire Branch of the British Foundrymen's Association a discussion took place upon the selection of iron for certain castings, the qualities of moulding sands, and the venting of moulds and cores.⁵

An illustrated description is given⁶ of the design and construction of a heavy flask for casting a cylinder 68 inches in diameter by 60-inch stroke, weighing 26 tons.

¹ *Mines and Minerals*, vol. xxxii, p. 565.

² *Eisen Zeitung; Castings*, vol. ix, p. 18.

³ *Engineering News*, vol. lxvi, p. 783.

⁴ *Power; Practical Engineer*, vol. xlv, p. 262.

⁵ *Ironmonger*, vol. cxxxviii, p. 484.

⁶ *Castings*, vol. ix, pp. 1-3.

T. F. Harlyman¹ describes and illustrates a cheap and effective method of multiple-moulding on an ordinary hand-pressed or an hydraulic moulding-machine, the only extra cost being in some cases an additional pattern-plate.

A. E. McClintock² describes a universal pattern-board devised to facilitate the mounting of split patterns for jarring machine use.

The method of moulding large slag ladles as carried out at the works of the Prime Steel Company of Milwaukee is described.³ Each ladle is a solid-steel casting and weighs 20,000 lbs., and is 10 feet 5 inches in diameter at the top and 8 feet 6 inches deep inside. The mould is made in a pit, the ladle being cast right side up.

An illustrated description is given⁴ of a method of moulding an external-flange cylinder, or large flange-pipe in loam.

An illustrated description is given⁵ of the moulding of an internal-flange cylinder in loam.

Details are given⁶ of an intricate iron mould for casting small projectiles, also a machine for making grate bars.

J. H. Eastham⁷ describes the moulding of a baffle plate of unusual shape.

A method of green-sand moulding without patterns is described⁸ and illustrated.

A system of storing patterns, and handling them as required, as practised at the works of the Falk Company, Milwaukee, Wisconsin, is described by C. A. Tupper.⁹

Pipe Moulding.—An illustrated description is given¹⁰ of the Herbert system of continuous pipe moulding and casting installed at the plant of James B. Clow & Sons, Coshocton, Ohio.

An illustrated description is given¹¹ of a process of casting iron pipes without cores, designed by H. Molinder. The process is carried out in a rotary mould, which, in operation, is revolved at such a speed that the centrifugal force throws the iron outward in the mould as fast as it is poured in, and in such a way that it flows out and produces a more even thickness than it is possible to obtain by other methods.

Foundry Cores.—An illustrated description is given¹² of a plant for the economical making and handling of foundry cores. Apart

¹ *Foundry Trade Journal*, vol. xiii. pp. 659-661.

² Paper read before the National Founders' Association; *Iron Trade Review*, vol. xlix. pp. 1013-1015.

³ *Canadian Machinery*, vol. viii. pp. 29-31.

⁴ *Foundry Trade Journal*, vol. xiv. pp. 80-82.

⁵ *Ibid.*, pp. 156-162.

⁶ *Iron Trade Review*, vol. i. pp. 947-950.

⁷ *Canadian Machinery*, vol. vii. p. 312.

⁸ *Eisen Zeitung*, vol. xxxii. pp. 741-742.

⁹ *Iron Age*, vol. lxxxviii. p. 330.

¹⁰ *Mechanical Engineer*, vol. xxix. p. 36.

¹¹ *Engineer*, vol. cxiii. pp. 497-498.

¹² *Canadian Engineer; Foundry Trade Journal*, vol. xiii. pp. 663-664.

from the general compactness of the plant wherein the coremaker's benches are close to the ovens, and near to both benches and ovens is a set of cooling and storage racks. Passing close to these in such a manner as to serve them all, is a conveyer, consisting of cars of two shelves each, suspended at about bench-height from an overhead rail, which serves for carrying green cores from the benches to the ovens, and baked cores from the ovens to the cooling and storage racks, cores from the storage racks to the moulders, and finally for returning core-boxes, driers, and trays to the coremakers' benches.

A. E. Outerbridge, Jun.,¹ describes a practical and rapid test for adulterations in core oils. A process of core-making different from that usually employed is now frequently used, particularly in the United States. The process consists of the preparation of a kind of quicksand by the intimate mixing of sharp sand and some vegetable oil (preferably linseed), in the proportion of 30 to 100 parts of sand to one part of oil. The mixture being mobile is poured into the core-box until it is well filled, any excess being scraped off by means of a straight-edge drawn across the top of the box. Provision is made for taking the box apart, thus leaving the fragile core ready to be carried to the oven without injury. These oil-cores are extraordinarily tough when baked, and are impervious to moisture. They require no venting, as but little tendency to form gas is manifested on pouring the metal. The high cost of the fine grades of vegetable oils has brought about the introduction of so-called core-oils which have a deleterious effect on the cores, and the author was led to devise a means for their detection.

H. M. Lane² deals with the equipment and management of the foundry core-room, and the materials used for core-making. The question of binders is also fully discussed, and the results of experiments on various materials are given. The author also gives a table of results of fineness tests of various sands.

J. J. Metzger, Jun.,³ gives details of the core-room practice in the foundries of a manufacturer of valves and pipe fittings, where a great variety of castings of all sizes and styles are made in large numbers.

W. J. May⁴ deals with the making of soft cores for tender castings.

A description is given⁵ of the Wadsworth core-testing machine for comparing the strength of different core mixtures as affected by changes in sand, oils, and binders.

An illustrated description is given⁶ of a machine for testing the strength of various core mixtures.

A description is given⁷ of the Hewlett sand core-making machine.

Core-room practice in German foundries is dealt with.⁸

¹ *Journal of the Franklin Institute*, vol. clxxii. pp. 591-609.

² *Journal of the American Society of Mechanical Engineers*, vol. xxxiii. pp. 1203-1282.

³ *Castings*, vol. ix. pp. 177-179.

⁴ *Practical Engineer*, vol. xlv. pp. 18-19.

⁵ *Canadian Machinery*, vol. viii. pp. 53-54.

⁶ *Castings*, vol. ix. pp. 111-112.

⁷ *Iron Trade Review*, vol. i. pp. 602-603.

⁸ *Castings*, vol. ix. p. 173.

Moulding Sand.—R. Mather¹ discusses the subject of testing the various properties of moulding sands. Methods in use at the present time are dealt with, and in some cases modifications are suggested. The author concludes that what is now required is a thorough scheme, very carefully planned and carried out, for investigating the reliability and usefulness of the tests, with the object of weeding out those which are unnecessary. Reliability and the needful degree of accuracy should be the essentials required of each test, but the important place in the scale of values should be given to quickness and simplicity, so that the foundryman should have no unavoidable difficulty in using and understanding the tests of his sands.

E. B. Gilmour² describes a method of mixing and using old sand for moulds and cores.

Moulding sands, and their application to various classes of foundry work, are dealt with.³

Moulding Machines.—W. Lewis⁴ discusses the principal types of moulding machines, and points out some of their limitations. He also compares the moulding of a certain pattern by hand and by machine, in order to emphasise the importance of time saving in the foundry. A series of illustrations are given showing the moulding of a wheel on a combination jarring and roll-over machine.

A moulding machine for light work, in which the jolt-ramming and squeezing principles of making moulds are combined, is described⁵ and illustrated.

What is believed to be the largest jar-ramming moulding machine ever built is described⁶ and illustrated.

A turn-over, power-draft moulding machine, in which separate cylinders are employed for turning over the mould and for drawing the pattern, is described⁷ and illustrated.

Chilled Castings.—T. D. West⁸ outlines a series of experiments to determine the effect of different methods of treatment in chilling or hardening cast iron during the process of cooling, after pouring the mould. The first experiments, showing how to produce mechanically mottled and white iron inside a grey body, led to experiments with chillers used in different ways, and with various other heat-absorbing or hardening media, such as air, charcoal, powdered manganese, or cyanide. A study is made of the effectiveness of chillers of different thicknesses and of different metals, and of the effect of cooling the chillers. The experiments indicate, among other results, that the accepted idea that chilling occurs entirely while the molten iron is

¹ Paper read before the Sheffield Branch of the British Foundrymen's Association, December 9, 1911; *Foundry Trade Journal*, vol. xiv. pp. 48-50.

² *Castings*, vol. ix. pp. 135-136.

³ *Foundry Trade Journal*, vol. xiv. pp. 38-40.

⁴ *Journal of the Franklin Institute*, vol. clxxii. pp. 227-251.

⁵ *Iron Trade Review*, vol. xlix. p. 742.

⁶ *Ibid.*, p. 832.

⁷ *Ibid.*, vol. l. pp. 547-549.

⁸ *Journal of the American Society of Mechanical Engineers*, vol. xxiv. pp. 837-862.

solidifying is wrong ; and they show how stronger grades of iron can be used for car wheels and rolls, and still obtain the desired depths of chill in such castings. They also demonstrate the superiority of air-cooling over metal chillers.

T. D. West¹ describes a series of tests relating to the relative strength of grey iron and of partly or wholly chilled iron, showing the best combination in chilled castings. Many tests are presented of chillable iron alloyed with vanadium and titanium. Previous to these tests, experiments were made for the purpose of establishing a size of round bars suitable for making tests of chillable irons where it is necessary to have the bars either of a uniform grey structure throughout or capable of being chilled throughout, the metal in each case being poured from the same ladle. The effect is shown on the results of tests of different bars in testing with regard to the quality or grain of the metal. Attention is called to the advisability of drop tests for cast iron, and to the complexity and sensitiveness of chillable iron mixtures, requiring care in mixing, casting, and testing.

Imperfect Castings.—B. Osann² criticises T. D. West's³ recent paper on the formation of gas cavities in castings.

Special Castings.—A. Trowbridge,⁴ in dealing with die castings, gives a brief summary of the development of the manufacture of small castings in steel moulds. He outlines the principles of this process of casting and of hand and automatic casting machines, and gives the composition and characteristics of the metals best adapted for use with reference to the effect of temperature and shrinkage, together with examples of comparative cost.

J. H. Eastham⁵ describes a method of casting machine rollers vertically.

E. Muller⁶ discusses in detail the value of cast-iron radiators such as are now largely used for warming houses and public buildings in Germany. The best methods of casting them are likewise detailed.

Burning-on in the Foundry.—J. S. Hughes⁷ gives the results of experiments carried out with a novel process of "burning on" to steel, devised by himself. The experiments were undertaken at an Indian works possessing a Tropenas plant, and were the outcome of new traffic conditions imposed upon the Indian railway companies by the Government. These conditions took the form of an order that, in view of the increasing loads of railway stock to cope with growing traffic, the axles used under certain waggons were to be of increased

¹ *Journal of the American Society of Mechanical Engineers*, vol. xxxiv. pp. 865-882.

² *Stahl und Eisen*, vol. xxxii. pp. 143-146, 346-350.

³ *Transactions of the American Foundrymen's Association*, 1911, pp. 39-61.

⁴ *Journal of the American Society of Mechanical Engineers*, vol. xxxiii. pp. 1467-1477.

⁵ *Canadian Machinery*, vol. vii. p. 283.

⁶ *Stahl und Eisen*, vol. xxxi. pp. 1951-1957, 2131-2134.

⁷ *Engineering*, vol. xciii. pp. 516-517.

section, and the journals increased by $\frac{1}{4}$ inch. As the size of the boss of existing wheels was such as to preclude the possibility of boring it out to take the new axle, the process of casting mild steel on to wrought-iron wheels was tried. The method of carrying out the experiments is described.

Casting of Stove Plates.—O. Johannsen¹ gives an interesting account of the preparation of ornamental cast-iron stove plates for public and private buildings. The article is illustrated with beautiful photographs of such plates, cast at various times, since A.D. 1508.

J. Lasius² also contributes an interesting paper on the early manufacture of ornamental cast-iron plates for stoves in private dwellings and public buildings on the Continent. The article is illustrated by beautiful plates illustrating the types of ornamentation—mainly scriptural—which were executed.

Steel Castings.—In discussing the subject of steel castings, H. Brearley³ points out that the coarse crystalline appearance which the fracture of a steel casting was supposed to have was not now a sufficient distinction between castings and forgings. The author considers it highly undesirable that unannealed castings should be brought into any kind of service where a good casting was necessary, and explains how, quite apart from the question of cooling stresses, they might be expected to fail. He also shows how the important question as to whether a casting had been successfully annealed could be determined by simple means. The cooling of metal as it passed from the fluid to the solid state was illustrated by a few instances occurring in simple shapes cast in chill moulds.

E. F. Lake⁴ describes and illustrates various methods of casting steel and alloys in a vacuum.

Aluminium Castings.—Some practical hints on the moulding and casting of aluminium are given.⁵

Cleaning of Castings.—W. T. Magruder⁶ gives the results of a series of practical tests of a sand-blast machine under the actual conditions of commercial practice. The tests were carried out on a Pangborn machine, the rough surfaces of pieces of cast iron which had been cast in one mould being blasted by air from which the moisture had been separated, with dried and screened new Cape May grit. The results show that—(1) for a distance of 8 inches and an angle of 45 degrees, the equivalent amount of free air delivered per minute, the iron removed, the sand discharged, and the sand used up

¹ *Stahl und Eisen*, vol. xxxii. pp. 337-342.

² *Ibid.*, pp. 519-526.

³ Lecture delivered before the London Branch of the British Foundrymen's Association, March 8, 1912.

⁴ *Iron Age*, vol. lxxix. pp. 119-124.

⁵ *Foundry Trade Journal*, vol. xiii. pp. 718-719.

⁶ *Journal of the American Society of Mechanical Engineers*, vol. xxviii. pp. 1691-1704.

per 100 cubic feet of free air flowing per minute, vary directly with the pressure; the amount of usable sand remaining and the amount of sand discharged per pound of iron removed vary inversely with the pressure; (2) for 60 lbs. pressure and 8 inches distance the largest amount of iron was removed and the least amount of sand was required to do it when the angle between the nozzle and the work was 45 to 60 degrees; (3) for 60 lbs. pressure and 45 degrees between the nozzle and the work, the largest amount of iron was removed, and the least amount of sand was required to do it when the distance was 6 inches; (4) the quantity of sand used varies with the directness of the blast, and (5) inversely with the distance from the test-bar.

A description and illustrations are given¹ of a sand-blast tumbling barrel apparatus, fitted with a sand separator and suction hoppers, for cleaning castings.

British Foundries.—A description is given² of the foundry at the Nautilus Works of Petters Limited, Yeovil.

American Foundries.—An illustrated description is given³ of the new continuous foundry of French & Hecht at Davenport, Iowa, for the manufacture of cast-iron hubs and boxes for wheels, which are produced in large quantities.

The general arrangement of the new malleable iron foundry of the Prescott Malleable Iron Co., Wisconsin, is described⁴ and illustrated.

Details are given⁵ of the equipment of the foundry of the Malleable Iron Range Company, Beaver Dam, Wisconsin, and the methods employed in the production of malleable iron stove plates are described.

H. C. Estep⁶ gives particulars of the equipment of the grey-iron foundry of the M. Rumely Co., La Porte, Indiana.

An illustrated description is given⁷ of the equipment of the foundry of National Brake and Electric Co., Milwaukee.

Details are given⁸ of the foundry equipment of the Best Manufacturing Co., Oakmont, Pennsylvania, for the manufacture of pipe fittings.

Details are given⁹ of the construction and arrangement of the new foundry of the International Harvester Co. at Springfield, Ohio.

L. G. Dennison¹⁰ describes the equipment of the Joliette Steel and Iron Foundry Co. Limited, of Joliette.

Use of the Microscope in the Foundry.—The importance of metallography in the foundry is dealt with, and the points of interest to practical foundrymen are reviewed.¹¹

¹ *Castings*, vol. ix. p. 25.

² *Engineer*, vol. cxiii. pp. 358-359.

³ *Iron Trade Review*, vol. xlix. pp. 729-735.

⁴ *Ibid.*, pp. 835-838.

⁵ *Ibid.*, vol. l. pp. 337-342.

⁶ *Ibid.*, vol. l. pp. 437-445.

⁷ *Ibid.*, vol. xlix. pp. 911-920.

⁸ *Ibid.*, vol. l. pp. 145-150.

⁹ *Ibid.*, pp. 233-239.

¹⁰ *Canadian Machinery*, vol. vii. pp. 324-325.

¹¹ *Eisen Zeitung; Castings*, vol. ix. pp. 108-110.

Accidents in Foundries.—W. H. Cameron¹ deals with the precautions taken by the American steel foundries for the prevention of accidents.

Foundry Costs.—G. E. Andres² discusses the keeping of records of foundry operations, and gives a chart for recording production costs.

C. J. Simeon³ discusses the scientific management of the foundry, and advocates the use of the slide-rule for settling piecework prices for moulding in large foundries.

In discussing the question of cost-keeping in foundries, the basis for a reasonable profit, and the method of ascertaining and applying the elements that should enter into a correct estimation of foundry work, are dealt with.⁴

¹ Paper read before the Pittsburg Foundrymen's Association, April 1, 1912; *Mechanical Engineer*, vol. xxix. p. 480.

² *Iron Trade Review*, vol. xlix. pp. 1053-1057.

³ *Ibid.*, vol. l. pp. 68-70.

⁴ *Eisen Zeitung, Castings*, vol. ix. pp. 104-105.

FORGE AND MILL MACHINERY.

Forging Presses.—A double-crank forging press, embodying a number of new features, is described and illustrated.¹ The machine is adapted for general forging work, including the forming of hammer heads, pick eyes, hatchets, and forgings required by makers of mining supplies and agricultural implements. One of the special features of the press is an entirely new design of counterbalance. The strains to which the housings are subjected are taken through bolts and the caps are cast in one piece, an arrangement which facilitates the easy removal of the crankshaft.

Recent improvements in the design of large presses for different classes of work are dealt with.²

A description is given³ of two Bliss presses for the production of cupped articles or shells by the drawing process.

Electric Driving of Rolling-Mills.—C. A. Ablett⁴ discusses some general principles involved in the electrical driving of rolling-mills. To ensure that the working costs of a rolling-mill should be low, means must be found for reducing the fluctuations in the power required for driving. The percentage variation in power changes with different weights of fly-wheel, and with various durations of pass and interval. Curves showing the variation of motor-power and speed for various sizes of fly-wheels are given, from which the following conclusions are drawn. If the time during which the pass lasts is short, and the interval is also short, light fly-wheels reduce the percentage power variation to a small value, whereas if the time of the passes and of the intervals is long, heavy fly-wheels are required. If the interval is short compared with the time of the pass, a light fly-wheel will serve, but where the interval is long compared with the pass, heavier fly-wheels must be used. In practice the question is not simple, because the various passes in rolling down a billet to a definite section require widely differing powers, and the time of passes and intervals also differ widely. The choice of the power of a rolling-mill motor and the weight of the fly-wheel so as to obtain that relation between power and fly-wheel weight that will reduce the cost of power

¹ *Iron Age*, vol. lxxxviii. p. 644.

² *Iron Trade Review*, vol. l. pp. 483-484.

³ *Ibid.*, pp. 915-916.

⁴ *Journal of the Institution of Electrical Engineers*, vol. xlviii. pp. 592-623.

to a minimum, depends on whether power is generated within the works or whether it is purchased from outside. In the latter case there are various systems of charging for power, which materially affect the most favourable proportions between motor and fly-wheel. Some typical cases, showing how the system of payment affects these proportions are considered, and the advantages of three-phase and direct current for merchant mill driving are compared.

C. A. Ablett¹ elsewhere discusses the electric driving of rolling-mills, and describes at considerable length some of the three-high mills electrically driven on the Ilgner system which have been installed on the Continent. He calls attention to the high speed at which it is possible to drive the mill. It is urged that much economy results from using the Ilgner system of driving three-high rolls. Bars can be got more rapidly through the mill than with other methods of driving, and they can be finished at a much higher temperature. Continental experience has shown that with three-high mills driven on the Ilgner system the output is from 20 to 30 per cent. greater than can be obtained ordinarily.

B. R. Shover² and E. J. Cheney, in discussing the economics of the electric driving of rolling-mill plant, consider it beyond question that induction motors should be used for driving the main rolls, but there is a diversity of opinion as to whether the auxiliary machinery should be driven by alternating or direct current. The authors find that—(1) the alternating current system costs slightly more than the mixed system, the excess first cost being higher for 22,000 volts transmission than for 6600 volts, and higher with gas-engines than with turbines; (2) the lower the power factor the greater is the excess cost of the all-alternating system; (3) the annual costs of the all-alternating current system considered are lower than those of the mixed system; (4) the actual operating costs are considerably less than those of the mixed system; (5) if the saving in output due to the fewer delays in the all-alternating current system is taken into account, the saving in costs will be largely increased.

An illustrated description is given³ of the electrical equipment of a 28-inch reversible cogging-mill installed at the works of Dorman, Long & Co., Middlesbrough. The mill is designed to reduce mild-steel ingots 12 inches square and weighing approximately 1 ton each to billets 3 inches square at the rate of 15 tons per hour. The mill itself consists of one stand of rolls and one pair of pinions directly connected to the shaft of the driving motor by a special sleeve coupling, designed to avoid the transmission of any severe thrust to the shaft and bearings. The motor is capable of giving a continuous output of 1200 brake-horse-power at a speed of 70 revolutions per minute, and a maximum torque corresponding to an output of 3600 brake-horse-power at the same speed. Current is supplied to the mill motor by a special reversible continuous-current generator which

¹ *Proceedings of the Cleveland Institution of Engineers*, 1911-12, No. 2, pp. 30-75.

² *Electrical World*, vol. lviii, pp. 793-794.

³ *Iron and Coal Trades Review*, vol. lxxiv, pp. 483-484.

forms part of a fly-wheel equaliser. The generator, which is capable of giving continuously an output of 1000 kilowatts at a pressure of 400 volts, is coupled directly to a three-phase induction motor of the slip-ring type, designed for a continuous output of 950 brake-horsepower at any speed between 400 and 480 revolutions per minute, when supplied with current at 2750 volts and 40 cycles per second. The fly-wheel has a weight of 30 tons and a peripheral speed of approximately 310 feet per second.

W. H. Lake¹ gives an illustrated description of the electrification of the mills at the Shelton Iron and Steel Works.

The electric-driving equipment of rolling-mills at the Lochin Works of William Bain & Company is described.²

W. Sykes³ gives particulars of the electrical equipment of the universal plate-mill at the works of the Illinois Steel Company, and also the results of five years' operation of this mill.

B. T. McCormick⁴ describes the electrical equipment of the reversing blooming-mill at the plant of the Algoma Steel Company, Sault Ste. Marie, Ontario.

A. S. Ahrens⁵ discusses the advantages of electric power for driving tube-making mills, and describes the practice at the plant of Spang-Chalfant & Co., Pittsburg, where small tubes are made by the butt-welding and large tubes by the lap-welding process.

Power Requirements of Rolling-Mills.—J. Puppe⁶ deals with the consumption of power in girder, wire, and plate rolling. Experiments were carried out at the Peine rolling-mills with the object of ascertaining what class of power was most economical for rolling girders. The results show that the maximum efficiency is obtained with electric power. Two trains were studied, a large one and a smaller. The former consisted of four three-high sets, 90 centimetres (36 inches approximately) in diameter, and 220 centimetres (82-86 inches) in length. The latter comprised three three-high sets 78 centimetres (31 inches) in diameter, and of approximately the same length. Separate tandem compound engines were fitted to each with fly-wheels weighing $8\frac{1}{2}$ and $7\frac{1}{2}$ tons respectively. The results obtained are given in the table opposite, from which several interesting points may be gathered. The elongation was calculated by dividing the main initial cross section by the final cross section. The steam consumption was measured by a Hallwachs meter. It will be observed that the consumption of steam per ton of final weight is a function of the output per hour, decreasing as the output increases. The temperature of the ingots is likewise an

¹ Paper read before the Staffordshire Iron and Steel Institute, December 16, 1911; *Iron and Coal Trades Review*, vol. lxxxiii, pp. 1007-1010.

² *Iron and Coal Trades Review*, vol. lxxxiv, p. 542.

³ Paper read before the American Institute of Electrical Engineers, April 25, 1912; *Iron Trade Review*, vol. I, pp. 960-965.

⁴ *Ibid.*, pp. 953-956.

⁵ *Electric Journal*, December 1911; *Iron and Coal Trades Review*, vol. lxxxiv, pp. 210-211.

⁶ *Stahl und Eisen*, vol. xxxii, pp. 6-12, 106-111.

Mill.	Standard Section No.	Final Sectional Area, Sq. Cm.	Ingot Section, Cm.		Weight of Ingot, Kilos.	Total Number of Passes.	Output per Hour, Tons.	Initial and Final Temperature, Degrees C.	Steam Consumption per Ton of Final Weight.
Large	I 50	179.0	Top. 42	Bottom. 46.5	2500	21	45	1310-1150	474
	" 42.5	132.0	40	44	2100	21	46.7	1322-1150	526
	" 36	97.0	40	44	2100	23	34	1300-1130	632
	" 34	86.7	40	44	2100	23	35.2	1310-1140	705
	" 32	77.7	37.5	40.5	1800	23	32	1295-1131	774
	" 28	61.0	35	38	1600	25	34.2	1290-1160	777
	" 23	42.6	31	36	1250	25	32	1254-1036	841
	" 22	38.5	31	36	1250	23	29	1322-1125	934
	I 22	37.4	31	36	1250	23	25.8	1310-1080	947
	I 19	30.5	29	32	1100	17	23.8	1300-1050	1200
Small	" 16	22.8	27	30	850	19	18.3	1295-1030	1337
	I 16	24.0	27	30	850	21	20.6	1295-1020	1328
	" 14	20.4	27	30	650	19	18.3	1310-1000	1404

important factor. The heaviest ingot fell through 160°C. , whereas the lightest ingot, initially at the same temperature (1310°C.) fell through 310°C. , or twice the amount. The experiments on wire-mills were carried out at Neuhoftnungshutte, and those on plate-mills at Dillingerhütte.

B. N. Westcott¹ describes the methods used in testing the power requirements of rolling-mills, both steam and electrically driven, the object in view being—(1) to secure a continuous record of the power required to drive the mill; (2) to secure a continuous record of events taking place in the mill, and (3) to connect definitely and positively the records of 1 and 2.

Pressure on Rolls of Rolling-Mills.—J. Puppe² discusses O. Zeller's recent proposal for regulating the pressure exerted upon the rolls during the rolling of sheet iron, and the avoidance of too high a pressure, with consequent unnecessary strain upon the machinery.

M. Herrmann³ discusses mathematically the theory of rolling, and formulæ are deduced from which it is possible to calculate the power required, the pressure produced between the rolls, &c.

Roll-Drafting.—B. Weissenberg⁴ deals in detail with the grooving of rolls. Attention is drawn to the difficulty of choosing the form to be employed which shall give the best results with the minimum expenditure of energy owing to the numerous factors involved, the temperature of working being one of the most important. For this reason results can only be expressed relatively to the various forms of roll employed, and not absolutely in terms of power required. The paper is well illustrated with diagrams showing the value of graphical methods of studying the problems.

British Rolling-Mills.—An illustrated description is given⁵ of the new electrically-driven rolling-mill at the Skinningrove Ironworks. The electricity is generated by alternators driven by engines operated by blast-furnace gas. A new application of blast-furnace gas in this country adopted by these works is that of heating the soaking-pits. The distance from the cogging-mill to the soaking-pits is 300 feet, and the ingots are rolled down to finished sections without being reheated. Siemens-Ilgner electrical equipment is used for driving the rolling-mill. The mill consists of a 36-inch cogging-stand, 36-inch roughing-stand, and a 36-inch finishing-stand, arranged in tandem and driven by one reversing-mill motor. The mill has a capacity for rolling ingots weighing 2 to 4 tons into rails, beams, and angles at a rate of about 30 tons an hour.

¹ *General Electric Review*, vol. 1. pp. 394-400; *Mechanical Engineer*, vol. xxix. pp. 300-303.

² *Stahl und Eisen*, vol. xxxi. pp. 1921-1926.

³ *Ibid.*, pp. 1706-1711.

⁴ *Ibid.*, pp. 1653-1662.

⁵ *Engineering*, vol. xcii. pp. 410-414.

An illustrated description is given¹ of an arrangement of driving-gear designed by A. Lamberton for two-high reversing rolling-mills in which, to avoid reversal of the direction of rotation of the rolls, the latter, constantly driven in one direction, are carried in housings which are capable of oscillation through 180° by means of rack and pinion gearing in gable-like end-frames, so as to reverse the relative positions of the rolls.

Canadian Rolling-Mills.—A description is given² of the plant of the Canada Steel Company of Hamilton, Ontario, whose speciality is the utilisation of old steel rails for the manufacture of agricultural implements and for other purposes. The rails which have a carbon content of about 0.40 per cent., are broken by hand into 7½ and 11-foot lengths, and are passed to a continuous-heating furnace heated by coal. A feature of this plant is that no steam is used for any purpose. The furnace ash-pits are water-sealed, and the dropping of the hot ashes into the water generates sufficient steam vapour to soften the clinker on the grate bars. The rail is pushed into the coolest part of the furnace by means of an electrically-driven feeder, and is fed into the furnace crossways; each advance of the feeder moves forward all the rails in the furnace, and on arrival at the other end they are ready for rolling. The rolling-mill consists of six sets of 12-inch three-high housings and one set of two-high housings. The first pass through the rolls separates the head, web, and flange of the rail. Each part is then passed through the various sets of rolls and made into finished bars at one heat. The head of the rail is rolled into rounds, squares, and flats, while the web and flange are mostly utilised for angles and shapes.

American Rolling-Mills.—The new merchant-mills of the Lackawanna Steel Company are described³ and illustrated. They consist of one six-stand 12-inch continuous roughing train, and four two-stand 10-inch finishing trains. The billets, which are 30 feet in length and 1¾ to 2½ inches square, are brought from the billet-mill on cars and handled by a crane, and weighed and introduced into the furnace by means of a Morgan conveyer of the usual type. The heating furnace is of the suspended roof continuous type, having a hearth 30 × 25 feet. The furnace is gas-fired, gas being furnished by four 10-foot Morgan gas-producers. After heating, the billets are delivered to the first stand of the continuous roughing-mill and a power-driven toggle-shear between the furnace and the roughing-mill shears them to proper length. This shear is arranged to operate independently on two separate lines of billets, cutting them as they are passing through the rolls. From the continuous roughing-mill the bar passes to the 10-inch finishing-mills.

¹ *Mechanical Engineer*, vol. xxviii. p. 703.

² *Canadian Machinery*, vol. vii. pp. 293-299.

³ *Iron Age*, vol. lxxxviii. pp. 690-691.

After passing through the finishing-stands the bar is delivered to a double cooling bed 360 feet long, of the Morgan inclined escapement type designed to handle sections from $\frac{1}{4}$ -inch rounds up to 3-inch wide flats. There are four pouring-type automatic reels for coiling wire, rods, nut-flats, and other sections. The reels mechanically discharge the coils on to a conveyer which delivers them to a hook carrier. The latter automatically takes the coils from the first conveyer and delivers them to any point on the loading-dock.

A motor-driven sheet- and strip-mill installed at the works of the Philadelphia Roll and Machine Company is described¹ and illustrated. The sheet-mill equipment consists of one stand of 20 × 36-inch two-high roughing rolls, and one stand of 20 × 30-inch two-high finishing-rolls, and a set of 20-inch two-high pinions. It was specially designed to meet the extraordinary heavy duty requirements encountered in this class of work. The area of the housing posts is 196 square inches, the housings being 7 feet 6 inches high, and the total width at the central point being 4 feet 8 inches. The total weight of the mill, including the gearing and one set of rolls, is 181,130 lbs. All the castings are made of a special charcoal air-furnace iron.

Ample provision has been made for the lubrication of the roll and the pinion necks because of the great pressure which the metal exerts upon them during the rolling process. To accomplish this, specially designed deep pockets were cored in the castings to retain the lubricant. The wearing parts are so constructed and fitted in position that they can readily be removed in case of wear and replaced at a very slight cost. The entire installation is driven electrically.

The rolling-mill equipment of the Portsmouth Steel Company, Ohio, is described² and illustrated. This consists of a 35-inch blooming-mill and an 84-inch three-high mill, an 18-inch three-high bar-mill, one 48-inch, one 60-inch, and one 66-inch jobbing-mill, five sheet-mills, and three stands of cold rolls.

The new rolling-mills and sheet and wire departments of the Youngstown Sheet and Tube Company, Youngstown, Ohio, are described and illustrated.³

Particulars are given⁴ of the rolling-mill plant of the Western Steel Corporation at Irondale, Washington. This consists of a 22-inch blooming-mill, a 14-inch merchant-mill, and a 9-inch finishing-mill. The mills are equipped to roll squares and rounds, from $\frac{1}{4}$ inch up to 4 inches, 20 feet long, flats up to 3 × 10 inches, and also angles and channels up to 7 inches.

A description is given⁵ of the new plate and merchant mill installed at the Haselton plant of the Republic Iron and Steel Company.

An illustrated description is given⁶ of the rolling-mill plant of the

¹ *Iron Age*, vol. lxxxviii, pp. 696-697.

² *Iron Trade Review*, vol. l, pp. 690-697.

³ *Iron Age*, vol. lxxxviii, pp. 630-637.

⁴ *Iron Trade Review*, vol. xlix, pp. 1003-1008.

⁵ *Ibid.*, vol. l, pp. 91-94.

⁶ *Ibid.*, vol. xlix, pp. 777-790.

Upson Nut Company, Cleveland, Connecticut. The equipment consists of a 34-inch blooming-mill and a semi-continuous finishing-mill of the Morgan type.

Details are given¹ of the arrangement of the roll-stands in the rail and merchant mills of the Minnesota Steel Company's plant at Duluth.

The new mill of the Laclede Steel Company, St. Louis, designed for the re-rolling of rails and billets into bars and shapes for agricultural implements, is described² and illustrated.

A description is given³ of a new type of mill for cold-rolling sheet metal.

Lighting of Rolling-Mills.—At the September meeting of the Association of Iron and Steel Electrical Engineers in New York in September 1911 papers by H. M. Gassman, C. J. Mundo, and W. Harrison were read dealing with the question of more effective methods of mill illumination.⁴

Mechanical Cooling Beds.—J. Schmitz⁵ describes some mechanical cooling beds recently introduced into Germany for the reception of hot bars straight from the rolls. Some of the beds are 90 metres long, and consist of bars of iron, plain and nicked, laid across at intervals like sleepers on a railway. The nicked bars are capable of rising a few inches above the plain ones, which latter are permanently fixed to the floor. The former then move in the direction of their length and hence transversely to the length of the bed for a short distance, equal to that between two consecutive nicks on the bars. They then sink below the plain bars and return to their original position. The hot bars from the rolls are brought to the side of the bed and laid on the permanent transverse bars. The nicked bars then rise and fall, and with each rise carry the hot bars a short distance across the cooling bed until they reach the opposite side, where they roll on to perforated iron plates and remain until required further.

Manipulators.—An account is given⁶ of recent improvements in rolling-mill manipulators.

The "Step" Process.—A. E. White⁷ gives details of experiments carried out by means of the Jones-Step process for the utilisation of the low-grade ores of the Kloman Mine, Michigan.

¹ *Iron Trade Review*, vol. I. pp. 349-352.

² *Ibid.*, pp. 743-747.

³ *Ibid.*, pp. 343-344.

⁴ *Iron Age*, vol. lxxxviii. p. 737.

⁵ *Stahl und Eisen*, vol. xxxi. pp. 1462-1466.

⁶ *Ibid.*, pp. 1534-1539.

⁷ *Iron Trade Review*, vol. I. pp. 655-656.

PRODUCTION OF STEEL.

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I.—OPEN-HEARTH PROCESS.

Open-hearth Practice.—B. W. Head¹ discusses recent developments in the open-hearth process.

Briquettes for Use in the Open-Hearth.—A new raw material for steelworks is described.² The product is sold commercially under the name of Swedish sponge, and is obtained by reducing briquettes of ore by means of carbon monoxide at a temperature below the fusion point of iron. Pure magnetite is employed, and the resulting briquette is of a bluish-black colour. Its composition is as follows:

	Per Cent.
Iron	96·6
Silicon	0·007
Phosphorus	0·012
Gangue	1·4 (chiefly silica)
Oxygen	1·02
Carbon	0·025
Manganese	traces

The shape adopted is that of a round briquette having a diameter of 270 millimetres and a thickness of 50 to 60 millimetres. Its density is 2. Owing to its porosity it requires special care in transport and storage. It is said to possess important advantages when used in the open-hearth furnace or in electrical furnaces, while its price is quite low.

Small Ingots.—G. Marton³ discusses the production of small ingots. Thirty-five ingot moulds constitute a battery, and these are filled and emptied together.

¹ *Journal of the West of Scotland Iron and Steel Institute*, vol. xix. pp. 272-288.

² *Revue de Métallurgie, Mémoires*, vol. ix. p. 304.

³ *Stahl und Eisen*, vol. xxxi. pp. 1918-1921.

Steelworks in France.—C. Bouvard¹ gives a description of the new steelworks of the Société Française de Constructions Mécaniques at Denain. There are two fixed-type open-hearth furnaces of 15 tons capacity each. Three producers have been installed for each furnace. Dimensional plans and drawings of the furnaces both in section and elevation accompany the description.

A description is given² of the Etablissements Arbel, Douai. There are two open-hearth furnaces, one being a basic furnace of 18 tons capacity, and the other an acid furnace of the Bidermann-Harvey type. A description is also given of the shops of the Fives-Lille works in the Nord.

Indian Steelworks.—An illustrated description is given³ of the mineral properties and steelworks of the Tata Iron and Steel Company of Sakchi, Bengal.

American Steelworks.—A description is given⁴ of the open-hearth steel plant of the Western Steel Corporation at Irondale, Washington. The basic process is used, the furnace bottoms being made of Austrian magnesite. Each furnace has a melting chamber 22 feet long and 11 feet 3 inches wide. Being designed for oil-burning there are two air regenerators under each furnace, 16 feet long, 12 feet 3 inches wide, and 14 feet 8 inches deep. The oil-burners are supported on the melting platform, and can be withdrawn from the furnace at will. The oil is atomised by steam, and is supplied under 60 to 80 lbs. pressure at 250° F. Two oil-fired ingot-heating furnaces are situated in front of the casting pit, and serve the purpose of soaking pits. The steel plant has an annual capacity of 42,000 tons of steel.

An illustrated description is given⁵ of the open-hearth plant of the Upson Nut Company, Cleveland, Connecticut. Steel is produced in four 60-ton basic furnaces fired with natural gas, which are also arranged to burn producer-gas. The working hearth of each furnace is 35 feet long, 13 feet 9 inches wide, and 4 feet 10 inches deep from the door-sill to the top of the bottom plate. The furnace has three port uptakes, two for air and one for gas. Each of the furnaces is served by an electrically-operated jib-crane for handling the tapping-spouts. Two sizes of ingots are cast, weighing respectively 5000 and 7000 lbs. The ladles into which the steel is tapped have a capacity of 65 tons.

The open-hearth plant of the Port-mouth Steel Company, Ohio, is described.⁶ Steel is produced in seven basic open-hearth furnaces of 60 tons capacity each.

¹ *Revue de Metallurgie, Mémoires*, vol. viii. pp. 647-654.

² *Comptes Rendus de la Société de l'Industrie Minière*, 1911, pp. 557-561.

³ *Iron and Coal Trades Review*, vol. lxxiv. pp. 675-679.

⁴ *Iron Trade Review*, vol. xlix. pp. 1003-1008.

⁵ *Ibid.*, pp. 777-790.

⁶ *Ibid.*, vol. l. pp. 691-697.

Scrap-bundling Machine.—A description is given¹ of a machine for bundling loose scrap, which operates with two distinct hydraulic presses, so that from 100 to 400 tons pressure is exerted, depending upon the weight of the finished bundle and the thickness of the metal handled. Another type of press is described,² which is capable of forming from 15 to 25 bales per hour, weighing from 2 to 3 tons.

Open-hearth Charging Machine.—An illustrated description is given³ of a charging apparatus for charging open-hearth furnaces, designed by B. W. Head.

Shears for Cropping Ingots.—A description has appeared⁴ of a machine for cutting off the waste ends of steel ingots, and for cutting ingots and forgings into short lengths to suit requirements.

Direct Production of Steel.—An illustrated description⁵ has appeared of two designs of an open-hearth gas-fired furnace for the direct production of iron and steel from iron ores. The main principle is the construction of the hearth of such a character as to resist the action of corrosive slags, and in such a manner that simultaneously, both from beneath and above, the contents of the hearth may be subjected to high temperatures equal to or exceeding 1600° C. The furnaces are the joint invention of W. S. Simpson and H. Oviatt.

Gas-Poisoning in Steelworks.—The Commission appointed by the Illinois Legislature to study occupational diseases in the industries of the State has issued a report⁶ on carbon-monoxide poisoning among steelworkers. A uniform deficiency in muscular powers was found to exist among workmen exposed to the gas, and this feature was so marked as clearly to indicate that the frequent contact of steelworkers with carbon monoxide caused a deterioration. The second startling development of the inquiry was that all the steelworkers examined seemed to be mentally below the average. It is stated that, in view of the fact that prolonged exposure to carbon monoxide may produce a profound impression on the nervous system, part of the sluggish mentality exhibited among the steelworkers may be due to frequent exposure to the gas. Amongst 900 employees of blast-furnaces, 65 severe and 216 mild cases of gas-poisoning occurred in the year 1910. The number of fatal cases is returned as 13 during the four years comprised in 1907 to 1910. Among 212 employees of boiler-houses there had been one severe, one fatal, and 55 mild cases of gas-poisoning.

¹ *Iron Trade Review*, vol. 1, pp. 155-156.

² *Ibid.*, p. 292.

³ *Practical Engineer*, vol. xlv, pp. 657-658.

⁴ *Iron and Coal Trades Review*, vol. lxxxiii, p. 768.

⁵ *Mechanical Engineer*, vol. xxviii, p. 711.

⁶ *Engineering and Mining Journal*, vol. xcii, p. 993.

II.—THE BESSEMER PROCESS.

Steelworks in France.—A description is given¹ of the Jordan steelworks belonging to the Denain and Anzin Company at Somain, France. The installation includes two mixers and four converters, which are capable of producing 1000 tons of steel daily. The converters have a capacity of 15 tons. The ingots are delivered to the rolling-mill on an electrical travelling-bridge. The mill, which consists of three trains of rolls, can turn out 1000 tons of finished rails and sections per shift.

American Steelworks.—The new steelworks of the Youngstown Sheet and Tube Company, Youngstown, Ohio, are described and illustrated.² From the blast-furnaces hot metal is carried in 40-ton ladle cars direct to hot-metal mixers, of which there are two with a capacity of 300 tons each. The hot metal is transferred from the ladles to the mixers by two 80-ton electric travelling-cranes, which have a 25-ton auxiliary hoist for pouring. The track from the mixer house to the Bessemer converter is laid parallel to the cupolas, the direct and remelted metal being handled by the same equipment. The hot metal is transferred from ladles to the pig machine by the mixer cranes, which place the ladles in a cradle while pouring. The pig machines discharge the metal into standard-gauge cars on the yard level. The Bessemer converting department is served by five cupolas, 10 feet 6½ inches diameter by 22 feet high, with a total daily capacity of 1500 tons. The soaking-pit equipment for the blooming-mill now consists of five 4-hole pit-furnaces, with a total capacity of 80 ingots.

Blowing-Engines.—A description is given³ of a turbo-blower installed at the plant of the Metallurgical Company of Sambre and Moselle, at Montignies-sur-Sambre, France, to supply the blast for four 15-ton Bessemer converters. The blower is able to compress from 5300 to 28,250 cubic feet per minute to pressures from 5·6 lbs. to 35·5 lbs. per square inch, and is driven by a turbine of 3750 horsepower, at a maximum speed of 2600 revolutions per minute.

Phosphates in Basic Slag.—E. Steinweg⁴ has studied the constitution of the tetrabasic phosphate of lime and its reducibility by means of iron containing carbon and pure iron. The results of his experiments show that silica reduces the tetrabasic phosphate in basic slag to a less basic phosphate, which is reducible by carbon. If the reaction takes place in the presence of iron, phosphorus is taken up by the iron. Alumina has also the effect of splitting up the tetrabasic phosphates of slags into less basic phosphates. It was endeavoured to determine the melting point of pure $4\text{CaO}\cdot\text{P}_2\text{O}_5$, which

¹ *Comptes Rendus de la Société de l'Industrie Minérale*, 1911, pp. 608–611.

² *Iron Age*, vol. lxxviii, pp. 633–634.

³ *Genie Civil*, vol. ix, pp. 294–295.

⁴ *Metallurgie*, vol. ix, pp. 28–40.

had been synthetically produced, but no crucible could be found of a material sufficiently refractory to withstand the temperature required; fluorspar was added for the purpose of lowering the temperature of fusion, but this only resulted in the attack of the crucible material, causing the loss of the melt. In the presence of ferric oxide the tetrabasic phosphate is split up into less basic phosphates, ferrite forming at the same time. Out of contact with silica, alumina, and ferric oxide, the tetrabasic phosphates in slag are not reducible by means of iron containing carbon.

III.—ELECTRIC PROCESSES.

Electric Furnace Construction.—In view of the many difficulties that have been presented in obtaining a suitable lining material for electric induction furnaces, a series of experiments¹ have been made, at the plant of the Poldihütte Tiegelgussstahlfabrik, with various linings in a pure induction furnace of the Kjellin type. In January 1908 this company put into operation a Kjellin furnace having a capacity of over 4 tons. High-class steel was produced by the basic process, and the lining first used was known as "Veit" magnesite. The furnace was not erected on a solid foundation, but was set on a carriage with provision for rotating the body of the furnace in either direction about a vertical axis. The rotation of the furnace necessarily generated considerable vibration, which resulted in the production of cracks in the lining to such an extent that it was found impossible to obtain more than 49 charges without renewing the lining. Various combinations were tried from time to time, and the life of the linings was gradually increased, until in 1909 the average was 200 charges per lining. Further improvements were made, until it was possible to obtain over 490 charges on one lining.

C. Hering² continues to discuss the thermal insulation of electric furnace walls, and summarises the data he has given in previous papers on the subject.

Consumption of Electric Energy in Electric Steel Furnaces.

—C. Hering³ calculates the electric energy necessary to maintain the temperature of molten steel constant. For a $\frac{1}{2}$ -ton furnace, 26 kilowatts per ton of steel are required; for a 10-ton furnace, 9·5 kilowatts; for a 50-ton furnace, 5·5 kilowatts per ton of steel.

Electric Production of Steel.—In dealing with the electric furnace process as applied to the metallurgy of steel, H. G. A. Stedman⁴ refers to the technical and commercial success of the electric process in

¹ *Iron Trade Review*, vol. xlix pp. 1015-1016.

² *Metallurgical and Chemical Engineering*, vol. x, pp. 97-102.

³ *Ibid.*, vol. ix, 590-592.

⁴ *Proceedings of the Cleveland Institution of Engineers*, 1911-1912, No. 3, pp. 78-145.

the production of steel castings. Not only can clean sharp castings be produced of any size and composition, but their behaviour under mechanical test is altogether in favour of the process. The author considers that, based upon the most recent figures, it should be possible in the ladle to produce metal for steel castings of the finest quality, with sulphur and phosphorus reduced to traces, at approximately £6 per ton if scrap is used, or £5 per ton when finishing molten metal from converters. It would appear that shipyard machine-shops and engineering works generally promise a wide sphere of usefulness for the small electric furnace of 1 ton and upwards, producing castings from waste material available such as scrap, trimmings, turnings, and borings. High-grade steel can be produced in the electric furnace in all respects equal to that produced by the crucible method, with the added advantage that it can be made very much cheaper, in any desired quantity, and without the use of expensive and comparatively scarce raw materials.

At the works of Le Gallais, Metz & Co., Dommeldingen,¹ where steel is manufactured by the electric process, it has been found feasible to reduce the sulphur content to as low as 0.005 per cent. The equipment of these works consists of three single-phase alternating furnaces and one three-phase furnace. The single-phase furnaces each have a capacity of $3\frac{1}{2}$ tons. The metal is first partially refined in a basic open-hearth furnace of 20 tons capacity. The charge consists of molten pig iron, the approximate composition being as follows: Carbon, 3.5 per cent.; manganese, 1.5 per cent.; silicon, 0.6 per cent.; phosphorus, 1.82 per cent.; and sulphur, 0.07 per cent. The finished product of the open-hearth furnace is a mild steel containing carbon, 0.15 per cent.; manganese, 0.25 per cent.; phosphorus, 0.045 per cent.; sulphur, 0.04 per cent.; and traces of silicon. The refining operation in the electric furnace proceeds until samples indicate the elimination of phosphorus, which usually takes about one hour. The composition of the metal is then as follows: Carbon, 0.05 per cent.; manganese, 0.10 per cent.; sulphur, 0.04 per cent.; and traces of silicon. The slag is then tapped and carbon is added. An amount of ferro-manganese corresponding to the desired manganese content is added at the same time, and immediately afterwards the desulphurising slag is added. As soon as the latter has melted, the bath and slag are deoxidised. The slag becomes perfectly white, and acquires the property of absorbing the sulphur liberated by the increased temperature. The particles of slag, gases, and sulphides separate out of the metal, and are taken up by the white slag, a small portion being volatilised. In other respects the composition of the metal remains unchanged. In making alloy steels the alloying metals are not added until after the deoxidation period, which lasts about one hour, in order to prevent loss in the slag.

W. Rodenhauser² discusses the production of electric steel, the effect of the price of current, the relative advantages of arc furnaces

¹ *Iron Trade Review*, vol. xlix. pp. 1017-1018.

² *Zeitschrift für angewandte Chemie*, vol. xxiv. pp. 2289-2302.

and induction furnaces, the useful applications of the electric furnace, and the electro-metallurgical process for the refining of steel.

F. C. Perkins¹ describes the refining of steel from Bessemer converters by a composite-electrode arc process. The main feature of this process is the use of a new composite electrode, one type of which consists of a carbon tube with iron core and a mixture of slag-producing materials surrounding the same. Other types have the slag material packed in an iron or steel tube or surrounding a carbon or iron rod, with or without projections for supporting the slag materials, using the usual binder employed in carbon electrodes. By the use of composite electrodes a large part of the slag material is introduced in a highly fluid state at the hottest points of the furnace, the rest of it being added in the usual manner. The molten metal continually circulates; all parts of the bath come in contact with the refining slag at the arcs and are rapidly refined.

The Melting of Ferro-Manganese in the Electric Furnace.—

F. Schroedter² draws attention to the loss entailed by the addition of solid ferro-manganese to the converter in ordinary steelworks practice, in consequence of small portions of the ferro-manganese becoming isolated in their passage through the slag and thus failing to sink completely through to the metal. Furthermore, the addition of the solid reduces the temperature of the liquid metal, and complete mixing of the two is rendered uncertain. For these reasons it is preferable to add molten ferro-manganese to the charge. Usually this is done by first melting the spiegel in a crucible in a solid or gaseous fuel furnace and then pouring the liquid contents into the converter. Whilst this reduces the loss referred to above, the advantages of this procedure are almost neutralised by the loss consequent upon the vaporisation of manganese from the crucible during melting. The author strongly recommends the electric furnace for melting the ferro-manganese, since its neutral or even reducing atmosphere prevents any appreciable loss of manganese, and the method thus possesses all the advantages of the previous one without its disadvantages. In addition to this, the actual cost of heating is considerably less than with an ordinary fuel furnace.

The electric furnace consists essentially of a crucible lined with dolomite or magnesite. In practice the lining is found to last for at least three months without renewal. The bottom of the crucible constitutes one electrode, the other being lowered through the roof. The best results are obtained by keeping the furnace always at work. The charge of ferro-manganese is added solid, and the movable electrode is lowered on to it. The charge when molten is tipped as required into small ladles, and added in the usual manner to the steel in the converter. The tilting of the electric furnace is most advantageously worked with hydraulic pressure.

¹ *Chemical Engineer*, vol. xiv. p. 406.

² *Stahl und Eisen*, vol. xxxi. pp. 1457-1462.

R. Korten¹ contributes an important paper on the melting of ferro-manganese in the electric furnace. He mentions that an electric furnace had been in operation under his observation since August 2, 1911, up to the time of writing (December 9), and although nearly 2000 tons of ferro-manganese had been treated, the lining of magnesite was still good, and likely to last another three or four months. In order to reduce the vaporisation of the spiegel the furnace is worked with a low voltage, and a uniform heating of a large area is aimed at rather than intense localisation of the heat. In order to reduce the cost, the bulk of molten spiegel should not be greatly in excess of the twenty-four hours' demand in the works, otherwise the cost of keeping the metal molten soon mounts up. Also a small amount of silicon is used in place of ferro-manganese, an alloy containing 76 per cent. of manganese and 4 per cent. of silicon being found advantageous.

Electric Furnaces of Special Types.—Particulars are given² of the Héroult electric furnace now in operation at the works of Lake & Elliot at Braintree. This furnace, which is of 2 tons capacity, is employed for the production of steel castings for automobile parts. The plant is at present the only works in England where an electric furnace is employed solely for foundry work. The generating plant consists of a gas-producer and a Westinghouse gas-engine, to which a single-phase alternator is directly coupled. The furnace is of the single-phase type, using two round electrodes 14 inches in diameter. The furnace is lined with magnesite brick and crushed dolomite, while the roof, which is removable, is lined with silica brick. The arc between the electrodes and the bath can be regulated either by hand or by Thury automatic regulators. The method of working the furnace is that regularly employed when melting and refining scrap in a Héroult furnace. When a sufficiently high temperature has been obtained the furnace is tilted electrically, a motor of 5 horse-power being employed. Steel from the furnace is received in a 2-ton bottom-teeming ladle, the actual casting being performed through the intermediate use of hand-shanks, and in the case of larger castings by direct casting from the ladle. The steel made is exclusively dead soft, between 0.1 and 0.15 per cent. of carbon, with manganese and silicon varying slightly according to the special mechanical properties required. Owing to the refining powers of the electric furnace the sulphur and phosphorus are extremely low, being together less than 0.03 per cent. As a result of the absence of sulphur the proportion of cracked or torn castings is reduced to a minimum.

T. D. Robertson³ discusses the advantages of the Grönwall steel-refining furnaces. The utilisation of two-phase current from a three-phase supply eliminates rotary transformers; an even distribution

¹ *Stahl und Eisen*, vol. xxxii. pp. 425-432.

² *Iron and Coal Trades Review*, vol. lxxxiv. p. 367.

³ *Metallurgical and Chemical Engineering*, vol. ix. pp. 573-575.

of heat is obtained throughout the charge, and at the same time a circulation of the molten metal is set up, resulting in improved refining conditions.

A. Hiorth¹ and F. A. Fitzgerald discuss the relative advantages of the Röchling-Rodenhauser and Hiorth furnaces.

J. Harden² describes recent developments in metallurgy, with special reference to the Paragon electric furnace, illustrations of which are given.

W. Lipin³ describes the Nathusius electric steel furnace, which he claims to be most suitable for the simultaneous heating of the slag, the bath, and the bottom, owing to the possibility of regulating the heating through the bottom electrodes.

An illustrated description is given⁴ of the Helberger electric transformer crucible furnace. The furnace consists of (1) a transformer, wound for any suitable voltage of supply; and (2) a water-cooled holding mechanism for the crucible, directly connected to the transformer and provided with carbon contacts. Melting takes place in ordinary graphite or charcoal crucibles, which are prepared by a special process. An ampere meter and a regulating switch complete the equipment, the whole being self-contained and ready for connection with an alternating-current supply system. An advantage claimed for the furnace is that by means of current regulation a wide range of heat is obtainable, which renders the furnace adaptable either for dealing with metals such as lead, brass, or platinum, or material such as quartz sand.

C. Myers⁵ discusses the principles of the electric furnace, and gives a brief description of the construction of the different types of furnaces now in operation, including the Héroult, Stassano, Girod, Kjellin, Röchling-Rodenhauser, Frick, and others. The author also gives data with reference to charges, additions, and power used on seven consecutive charges from an 8-ton Röchling-Rodenhauser furnace; also analyses of steel and slag taken at different periods of heat from a Héroult furnace.

Statistics of Electric Furnaces.—It is stated⁶ that the total number of electric furnaces in existence or in course of construction in the world for treating iron and steel is 120. Divided into the classes of arc furnaces, induction furnaces, and combination arc-resistance furnaces, these are as follows:—

¹ *Metallurgical and Chemical Engineering*, vol. x, pp. 71-72.

² Paper read before the Faraday Society, October 2, 1911; *Metallurgical and Chemical Engineering*, vol. ix, pp. 595-596.

³ *Ibid.*, vol. x, pp. 227-232.

⁴ *Foundry Trade Journal*, vol. xiv, pp. 24-25.

⁵ Paper read before the Manchester Association of Engineers, January 27, 1912; *Iron and Coal Trades Review*, vol. lxxxiv, pp. 178-179.

⁶ *Moniteur des Intérêts Matériels*, July 16, 1911, No. 85, p. 2465.

	Active.	Idle.	Building.	Totals.
Arc furnaces	51	7	25	83
Induction furnaces	26	1	8	35
Combination arc-resistance	2		..	2
Totals	79	8	33	120

Classified according to system these furnaces are as follows :—

	Active.	Idle.	Building.	Totals.
<i>Arc Furnaces—</i>				
Hérault	19	.	15	34
Girod	14		4	18
Stassano	5	7	1	13
Keller	4	.	2	6
Chaplet	4	...	1	5
Aktiebolaget Elektrometall	2		2	4
Hickman (own system)	1	.		1
Scott-Anderson (own system)	1	.	...	1
Firminy	1		..	1
<i>Induction Furnaces—</i>				
{ Kjellin	10			31
{ Röchling-Rodenhauser	10	1	8	
{ Kjellin-Colby	2			
Frick	1			1
Hiorth	1			1
Chatillon-Commentry	1			1
Schneider	1	.		1
<i>Combined Arc and Resistance Furnaces—</i>				
Nathusius	2	..	...	2
Totals	79	8	33	120

FURTHER TREATMENT OF IRON AND STEEL.

Case-Hardening.—G. Charpy¹ and S. Bonnerot have made a further series of investigations on the cementation of iron by solid carbon. Their earlier experiments showed that solid carbon does not cement iron *in vacuo*, but since Weyl's subsequent observations led to different conclusions it was determined to undertake new experiments. Graphite which had previously been carefully purified was placed between plates of extra mild open-hearth steel, which were pressed together at a pressure of 3000 atmospheres so as to ensure the closest possible contact. The plates were then heated under reduced pressure, and the gases were drawn off by a vacuum pump. It was found impossible to remove the gases entirely, but by careful working of the pump the pressure could be maintained for a long period between the desired limits. Six specimens were heated at 950° C. for periods varying from 10 to 38 hours, and the results showed that cementation did not take place if the pressure was kept at 0.1 to 0.3 millimetre, but if it rose above 0.5 millimetre, distinct carburisation occurred. The authors consider that their former results are thus confirmed, and that carbon will not cement iron at temperatures about 950° if care is taken to remove all gases capable of acting on the iron.

L. Guillet² discusses in detail the theory and practice of case-hardening. During the process it is the outer layers of the metal which become most highly carburised, the percentage of carbon falling as the distance from the surface increases. This is easily shown, both chemically and microscopically. For carburisation to take place the iron must be completely converted into the γ variety, in which variety alone carbon is soluble to any extent. The metal must therefore be heated to at least the A_{c_3} point, in practice the lowest temperature being 850° C. The substances producing carburisation must be such as readily part with carbon, and can be divided into three groups, namely (1) gaseous bodies, such as hydrocarbons, carbon monoxide, and cyanogen; (2) liquids, such as molten cyanides; and (3) solids, like free carbon, cyanogen derivatives, &c.

In successful practice both the temperature and the time of

¹ *Comptes Rendus*, vol. cliii pp. 671-673.

² *Comptes Rendus*, vol. lxx. pp. 153-163, 183-187, 203-207, 226-229, 241-247, 266-269, 286-288.

exposure should be accurately known—two highly important factors, which, however, are difficult to determine in large furnaces. The composition of the metal has likewise an important influence on the rate of carburisation of the metal. Thus, those elements which themselves readily yield double carbides accelerate the absorption of carbon: such are chromium, tungsten, molybdenum, and, in certain definite amounts, vanadium. Other alloying elements, such as nickel, silicon, and aluminium, retard carburisation to a marked extent. The microscopic structure of the steel is correspondingly affected. The resulting metal requires careful tempering, rules for which are given.

If a superficially hard metal is required, it is usual in practice to choose a soft metal of the following composition:

	Per Cent.
Carbon	<0.10
Manganese	<0.40
Sulphur	<0.04
Phosphorus	<0.05

If still greater hardness is required, a low carbon chromium steel may be employed, containing 0.75 to 1.0 per cent. of chromium. This yields a very hard and also a tough metal. If exceptional toughness is required a nickel steel is chosen, but the hardness is reduced. The carbonaceous powder employed may be made according to many recipes. A mixture of 60 parts of wood charcoal and 40 parts of barium carbonate gives good results, and has the double advantage of being easily prepared and having a low cost. It can also be used over again an indefinite number of times, provided its composition is regulated as occasion demands.

Steel containing vessels are largely used, but are attacked in the furnace, lasting only about 110 to 130 hours at 1000° C., or about 200 hours at 850° C. Hence their cost is an important item.

The finished metal is liable to many imperfections. Sometimes patches of uncarburised metal appear. This is often due to irregular laying of the carburising powder. The worst cases are those in which the metal becomes too highly carburised, consequent upon too high a temperature or too prolonged an exposure. Irregular carburisation is a further difficulty.

H. de Nolly¹ and L. Veyret have made experiments to ascertain the nature of the inflammable gases which are evolved during case-hardening. These gaseous evolutions are sometimes sufficiently energetic to cause explosions. The experiments consisted of analysis of the charcoal dusts and other cementing materials, determinations of the volumes of gases disengaged on the heating of such cements to a temperature of about 1100°, analysis of the gases produced at various stages, and experiments carried out at temperatures of 850° and at 1050° with the object of ascertaining the influence of the composition of the gases on the depth of the case-hardening.

In order to diminish the effect of the explosions the following

¹ *Revue de Metallurgie, Mémoires*, vol. ix. pp. 53-60.

precautions should be taken : (1) The avoidance, as far as possible, of cements containing animal or vegetable matter, which give an abundant flow of gas at low temperatures. (2) The employment, by preference, of wood charcoal carbonised at a fairly high temperature and mixed with 30 to 50 per cent. of barium carbonate. The evolution of gas is much less voluminous and the proportion of hydrogen lower. The activity of the case-hardening material appears to be a little lower at low temperatures, but at 1000° to 1100° the difference is negligible. A mixture of ordinary wood charcoal and coke, or of used cementing material mixed with barium carbonate, may be employed. (3) It is necessary to heat up slowly to 700°. By this means the air contained in the cement escapes, and the sudden evolution which occurs at about 700° is diminished.

The case-hardening experiments brought out the influence of hydrogen. As regards depth of penetration of case-hardening, this gas appears less injurious than might have been believed. Nearly all the cementing materials gave practically the same depth of carburised case, no matter what proportion of hydrogen was present. The least active cementing materials are : (1) Pure wood charcoal for case-hardening carried out at 1050°. (2) Mixtures of barium carbonate and coke for case-hardening at 850°. The large amount of hydrogen which was found in the gases disengaged by most of the cementing materials doubtless serves to explain a fact observed by many experimenters, namely, that the core of the case-hardened pieces often shows before annealing or quenching a coarser grain and greater brittleness than other pieces of the same chemical composition, which have been heated for the same period of time to the same temperature, but not case-hardened, and it is probable that when this injurious influence is not observed, cementing materials have been employed which either disengage no hydrogen or very little only. The experiments also showed that hydrogen is much more dangerous than nitrogen, and that to its presence might be attributed numerous defects in the steel which hitherto had been regarded as of obscure origin, such as extreme brittleness and hard particles found in places, which microscopic examination proves to be composed of almost pure ferrite, and are really the junctions of welding of former blowholes filled with hydrogen which has carburised the metal at the high temperature of forging. It was experimentally proved that hydrogen strongly decarburises steel at a temperature of 800° to 900° and renders it as brittle as glass.

A method of case-hardening, where certain parts of the work require to be glass-hard while it would be of great advantage to retain other parts soft, is described¹ with reference to the case of the mandrels of certain lathes that were dealt with in this manner.

Case-hardening Furnaces.—A description is given² of the new case-hardening furnaces at the plant of the Warner Manufacturing

¹ *Foundry Trade Journal*, vol. xiv. p. 169.

² *Iron Trade Review*, vol. xlix. pp. 773-774.

Company, Toledo, Ohio. The equipment consists of a battery of five case-hardening furnaces with heating chambers, 34×72 inches, and two heat-treating furnaces with heating chambers, 32×48 inches. The blast is furnished by a direct motor-driven steel fan pressure blower, and a rotary oil-pump is geared to the blower shaft. One oil-burner is required for each furnace. These burners are placed in front of the furnaces, parallel with the combustion chambers, and an auxiliary air-blast enters the opposite end of each furnace, which is intended to take the place of a baffle.

Hardening Furnaces.—S. N. Brayshaw¹ compares the relative advantages of gas-fired furnaces for heating steel objects in contact with air, and furnaces containing a bath of liquid. A mixture of fused salts is a more suitable heating liquid than molten lead, because the salts, owing to their comparative lightness, circulate freely, and, measured by bulk, they are much cheaper than lead. Suitable mixtures may be made which have about the same specific gravity as an ordinary fire-brick, in which the steel articles will sink. A well-proportioned mixture is non-poisonous, and has no injurious action on the steel. The waste by volatilisation is so slight as to be negligible, and there is no loss due to oxidation. The salts are less severe in their action than lead, and cannot possibly adhere so as to be difficult of removal, as often happens with lead. Pyrometers, which in atmospheric furnaces do not necessarily show the temperature of the work, will indicate it with precision in a bath furnace, as the temperature of the article in the bath is the same as that of the liquid if sufficient time is allowed.

A lead and salt bath furnace² for hardening or melting metal, designed by Fletcher, Russell & Co., Limited, is so arranged that a regular temperature is obtained, and the burning or overheating of the contents of the crucible is prevented. A fireclay jacket is placed between the crucible and the interior of the fireclay casing of the furnace, with a space between the casing and the jacket and a space between the jacket and the crucible; burners being so arranged that they will pass up the space between the casing and the jacket over the top of the latter and descend into the space between the jacket and the crucible, thereby circulating round the crucible which rests on a support, and passing finally to the flue at the bottom of the furnace.

E. A. Dixie³ gives an illustrated description of the hardening-room equipment of the Waterbury Farrel Foundry Company, Waterbury, Connecticut.

Annealing Furnaces.—A description is given⁴ of an oil-burning annealing furnace erected at the works of the American Steel Foundries, Indiana Harbours, Indiana. The furnace is used for anneal-

¹ *Engineering Magazine*, vol. xiii. pp. 233-237.

² *Mechanical Engineer*, vol. xxix. p. 267.

³ *American Machinist*, vol. xxxv. pp. 732-733.

⁴ *Iron Trade Review*, vol. i. pp. 342-343.

ing manganese steel castings. The furnace is charged with about 6 tons of castings, which are raised to a temperature of 1825° F., soaked for two hours, and then quenched in water. In operation there is no flame in the furnace chamber to strike the castings, the flame being diverted by wedge-shaped blocks placed directly in front of the burners. The oil is delivered to the burners at a pressure of 15 lbs. per square inch, and at a temperature of 100° F. The air is delivered at a pressure of 20 oz. and at a temperature of 400°.

A description is given¹ of an internally-fired rotary furnace, using oil fuel, for annealing and hardening steel. The furnace has a smooth internal surface and is mounted in such a manner that its longitudinal axis can be varied in inclination to the horizontal, this inclination allowing the material to move forward under gravity from the upper or feeding end of the furnace to the lower or discharge end. By varying the angle of inclination, the rate of feed can be changed and hence the time during which the metal is heated. The pieces are fed continuously into the upper end of the cylinder, if necessary, by the use of a carrying or buffer storage hopper, and come into contact with the revolving heating surface, thus absorbing heat from the refractory brick lining as well as from the heated gases.

L. Kentnowski² discusses the heating of furnaces on the regenerative principle, and describes the Hermansen system of regenerative heating suitable for annealing furnaces.

G. K. Hooper³ discusses the various mechanical handling devices and the general lay-out of annealing shops in malleable-iron foundries.

Reheating Furnaces.—A description is given⁴ of the Kroell reheating furnace. This consists of a sloping skid hearth, a welding hearth, and a grate situated in front of the latter. The gas generated on the grate undergoes complete combustion in consequence of the admission of a secondary supply of air which enters below the main vault of the furnace. This secondary air is heated in cast-iron boxes arranged in brickwork surrounding the grate, and divided into different compartments to compel the air to traverse a long course and remain in contact with the hot portions of the grate for some considerable time. Particulars of tests with this furnace are also given.

M. Philips⁵ discusses the combustion taking place during the working of a reheating furnace.

The Gordon-Pral continuous-heating furnace which utilises oil or gas for fuel is described⁶ and illustrated. The burners of this furnace are distributed along the roof, and the gases impinge upon the sloping portions of the roof, thereby being deflected longitudinally along the furnace instead of across its width, as is generally the custom. Three

¹ *Practical Engineer*, vol. xlv, p. 311.

² *Iron and Coal Trades Review*, vol. lxxviii, p. 933.

³ *Iron Trade Review*, vol. xlix, pp. 833-834.

⁴ *Iron and Coal Trades Review*, vol. lxxxiii, p. 723.

⁵ *Stahl und Eisen*, vol. xxxii, pp. 13-15.

⁶ *Iron Trade Review*, vol. l, pp. 911-913.

of these furnaces have been installed at the plant of the Republic Iron and Steel Company for heating rods.

Heat Treatment of Steel.—K. Friedrich¹ discusses the value of thermal analysis in commercial smelting operations, and in other processes involving high temperatures—the arrests observed in the heating or cooling curves affording valuable information as to the temperatures at which physical or chemical changes begin in the substances studied. When, for example, iron oxide and carbon are heated together in an atmosphere of nitrogen, a break in the continuity of the curve is observed at about 900° C., indicating heat evolution consequent upon the reduction of the oxide.

In a lecture on tool steels delivered before the Coventry Engineering Society, H. Brearley² described the changes which take place during the heating and cooling of steels, and drew special attention to the numerous ways in both these operations by which tools become defective. He also dealt with the various conditions which favoured the formation of cracks in tools, more particularly during the hardening operation, and strongly advocated research into their origin.

J. V. Emmons,³ in dealing with the structure and heat treatment of tool steel, discusses the microscopic constituents and the effect of annealing and quenching.

J. H. Herron⁴ describes the equipment of a plant and the methods employed for the heat treatment of steel, with special reference to the treatment of low carbon steels.

Particulars are given⁵ of a method of hardening steel by infusion.

R. Börnecke⁶ describes an electrical arrangement for heating metal tires uniformly for the purpose of expanding them previous to fixing them on wheels.

Hardening Temperatures of Tool Steel.—W. S. Sullivan⁷ gives a classification of tool steels according to grade, carbon content, and the purpose for which they are required. He recognises five classes of steel which he denotes by five temper numbers which should contain carbon in the following percentages:

	Carbon per Cent.
1	0.7 to 0.8
2	0.8 to 0.9
3	0.9 to 1.0
4	1.00 to 1.15
5	1.15 to 1.25

¹ *Stahl und Eisen*, vol. xxxi. pp. 1909–1917, 2040–2046.

² *Mechanical Engineer*, vol. xxviii. p. 776.

³ Paper read before the Metal Trades Superintendents and Foremen's Club of Cleveland, U.S.A., February 17, 1912, *Iron Trade Review*, vol. i. pp. 450–452.

⁴ Paper read before the Metal Trades Superintendents and Foremen's Club of Cleveland, U.S.A., November 18, 1911; *Iron Age*, vol. lxxxviii. pp. 1140–1144.

⁵ *Iron Trade Review*, vol. i. p. 436.

⁶ *Stahl und Eisen*, vol. xxvii. pp. 435–438.

⁷ Paper read before the New York Railway Club, November 17, 1911, *Engineering and Mining Journal*, vol. xcii. pp. 1216–1217, *Iron and Coal Trades Review*, vol. lxxxiv. p. 12.

No. 1 is suitable for crow-bars, pinch-bars, pick-points and wrenches, sledges, hammers, and rivet sets. The steel should not be heated above 1800° F. for forging. It should harden at 1485°, and should be capable of being annealed at 1300° to 1350°. No. 2 is suitable for track and boiler-makers' tools. It should not be heated above 1800° F.; can be hardened at 1480° and annealed at 1300° to 1350°. No. 3 is suitable for cold and hot chisels and rock-drills, shear blades, and punching tools. It should not be heated above 1750° F.; can be hardened at 1465° and annealed at 1300° to 1350°. No. 4 is suitable for machine drills and general machine-shop drills, lathe tools, taps, dies, and reamers. It should not be heated above 1700° F. for forging; can be hardened at 1460° and annealed at 1300° to 1350°. No. 5 is useful for brass-cutting tools and general small machine-shop tools, and should not be heated above 1700° for forging. It can be hardened at 1455° and annealed at 1300° to 1350°.

S. N. Brayshaw¹ discusses the best method of quenching carbon steel after correct heating for hardening. Experiments were made showing the effect of changes of temperature in the quenching bath; and the author also considers the boiling-point of water in relation to its quenching capacity, the effect of stirring during quenching, the effect of adding acid or salt to the quenching bath, the results of very quick quenching, of quenching in oil and in mercury. Mercury is greatly inferior to water as a quenching medium, chiefly on account of its very low specific heat and its greater density, which makes it less easy to agitate the object to be hardened.

F. Walker² deals with the hardening and tempering of carbon steel tools.

Rolling Iron and Steel.—F. Munker³ discusses the rolling of thin iron bars of various shapes—namely, circular, square, T-form, and numerous other shapes for special purposes. The use of 3-high rolls and of pairs of 2-high rolls is advocated, and copious diagrams drawn to scale illustrate the most convenient arrangements for particular purposes. For simple forms, such as round and square bars, 3-high rolls are recommended, the middle roll remaining fixed. For T-shaped bars or angles a pair of 2-high rolls is required.

K. Neu⁴ deals with some interesting phenomena observed during the rolling of steel in the rolling-mill.

R. B. Woodworth⁵ gives an historical account of the manufacture and design of iron and steel beams and girders.

Manufacture of Tubing.—J. F. Springer⁶ describes a method of manufacturing tubing by a process of rolling sheet-metal and subse-

¹ *Engineering Magazine*, vol. xlii, pp. 393-399.

² *Canadian Machinery*, vol. viii, pp. 26-27, 61-62.

³ *Stahl und Eisen*, vol. xxxi, pp. 1620-1624.

⁴ *Ibid.*, vol. xxxii, pp. 397-399.

⁵ *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xxviii, pp. 11-81.

⁶ *Machinery*, vol. xviii, pp. 361-362.

quently welding with oxygen and acetylene. The process is continuous, and a special welding-machine is used.

Forging.—The plant of the Canada Forge Company, Limited, Welland, Ontario, for the production of heavy forgings is described.¹

H. Ostwald² discusses the question of the production of small articles such as spanners, &c., in large quantities by special rolls.

Turning Steel Ingots to remove Surface Flaws.—C. Peipers³ discusses the advantages of casting steel ingots in cylindrical form when they are destined to be used in the manufacture of numerous relatively small articles. Surface impurities can then be easily removed by turning the ingots before rolling.

Electro-Magnets for Handling Material.—E. C. Ibbotson⁴ states that the first horse-shoe type of electro-magnet is now being superseded by the pot magnet, of which the Witton-Kramer is an example. The coil of this magnet is mechanically protected by a solid shell of special high permeability steel in which it is enclosed, and is weather-proofed by vacuum drying and impregnating under pressure with hot bitumen.

Electric Welding.—A description of the Kjellberg arc-welding process is published.⁵ Instead of a carbon electrode Kjellberg uses an electrode consisting of a metal core encased in a material, the constituents of which are intended to prevent the inclusion of foreign matters in the weld. The electrode also contains a practically non-fusible substance which forms a reducing atmosphere round the arc and prevents oxidation of the weld. Continuous current is employed at about 100 volts, the arc taking about 120 amperes. Results show that specimens of rectangular section with an area of about one-half square inch when welded had a yield point of 16·71 to 17·28 tons per square inch, with a percentage elongation in 2 inches of 6·5 to 12·5. The material originally had a yield point of 17·20 tons and elongation of 36·3 to 44·3 per cent. in 2 inches.

The arc-welding plant of the Pittsburg Railway Company is described.⁶ The apparatus is used for repairing all kinds of constructional work except parts consisting of cast iron. The electrodes are generally of carbon, but for light work, such as welding sheet-steel, an electrode of cold-rolled steel is used, the melting of which provides the additional metal required. In welding a flux is used, the following mixture having been found to give satisfactory results. Borax, 17 parts; brown oxide of iron, $1\frac{1}{2}$ parts; red oxide of iron, $1\frac{1}{2}$ parts.

¹ *Canadian Machinery*, vol. viii. pp. 9-10.

² *Stahl und Eisen*, vol. xxxii. pp. 104-105.

³ *Ibid.*, vol. xxxi. pp. 1927-1928.

⁴ Lecture before the Sheffield Society of Engineers and Metallurgists, *Lundry Trade Journal*, vol. xiv. p. 25.

⁵ *Engineering*, vol. xcii. p. 712.

⁶ *Electric Railway Journal*, vol. xxxviii. p. 1059.

Statements are given showing the economies which have been effected by the adoption of this method of executing repairs.

The Thomson electric welder, designed for the butt-welding of all classes of material, is described and illustrated.¹

Autogenous Welding.—J. F. Springer² describes an acetylene blowpipe for cutting and welding iron and steel. On the machine three jets are arranged in a rigidly vertical position, the gases being driven directly downward. In front is a heating-jet of oxygen and acetylene; at the rear is another but smaller heating-jet. Between the two the cutting-jet of oxygen is arranged. An oxygen and an acetylene tube together supply the gases for the two heating-jets. Thus these jets are both supplied from the same sources. An independent oxygen supply is provided for the cutting-jet, for the reason that ordinarily the back pressure of this jet is higher—and sometimes much higher—than is the case with the heating oxygen. The forward jet provides heat for the metal, which is probably lost by the time the pure-oxygen jet comes into play. This jet may be only $\frac{3}{4}$ inch behind. Still it would seem that conduction would carry off a considerable amount of heat while the cutting-jet is getting to the spot, especially where the movement is a slow one, as with very thick steel. The rear jet provides additional heat and thus reduces dissipation by conduction. Its sphere of operation is in the region where much of the wasteful conduction would take place. In the case of thin plates the rear jet is scarcely necessary, and may be shut off.

E. H. White³ deals with the considerations affecting the design and choice of suitable apparatus for oxy-acetylene installation, and gives the rules of the National Board of Fire Underwriters of Chicago covering such installations.

H. Cave⁴ deals with the oxy-acetylene process of welding and cutting, with special reference to the Davis-Bournonville equipment.

L. G. Dennison⁵ describes some welding and cutting operations carried out by means of the oxy-acetylene blowpipe.

A description has appeared⁶ of apparatus used in the Cyclone oxy-acetylene welding process.

H. W. Jacobs⁷ deals with the method of welding locomotive parts in the shops of the Atchison, Topeka, and Santa Fé Railway.

H. R. Cobleigh⁸ discusses modern welding processes. Autogenous welding has become the accepted name for arc flame and sometimes thermit welding, but, strictly speaking, the term means either self-welding, which is ridiculous, or welding with the same metal, whereas

¹ *Iron Age*, vol. lxxxviii, p. 329.

² *Ibid.*, pp. 472-473.

³ *American Machinist*, vol. xxxv, pp. 686-688.

⁴ Paper read before the Pittsburg Foundrymen's Association; *Iron Trade Review*, vol. 1, pp. 205-206.

⁵ *Canadian Machinery*, vol. vii, pp. 295-297.

⁶ *Iron and Coal Trades Review*, vol. lxxiii, p. 850.

⁷ *American Machinist*, vol. xxxv, pp. 913-916.

⁸ *Journal of the American Society of Mechanical Engineers*, vol. xxxiv, pp. 7-37.

two different metals are often united, sometimes even with a third metal. In the real sense of the word it is not welding, for there is no compression or hammering, except incidentally, in the belief that it improves the structure of the added metal. The simplest definition of autogenous welding is the uniting of metals by heat alone. Of the different kinds of torch or blowpipe welding, the two of chief commercial importance are the oxy-hydrogen and the oxy-acetylene systems. The oxy-hydrogen process is the older but has not been developed quite as rapidly, although for certain applications it has the advantage of its competitor. Where the greater heat intensity of the oxy-acetylene torch is of no advantage, the oxy-hydrogen with a temperature of about 4000° F. gives as good results, or even better. Another advantage is that it makes use of a by-product of the electrolytic decomposition of water, one of the best methods for procuring the purest oxygen, and a process that is becoming an important one commercially for making oxygen for the acetylene torch as well. Further, hydrogen can safely be compressed into tanks for supplying the portable outfits, whereas acetylene must be dissolved in acetone to be handled safely when compressed above two atmospheres. The ideal arrangement would seem to be the providing of all three gases, oxygen, hydrogen and acetylene, employing apparatus for the electrolytic production of the first two gases and an acetylene generator, and using the oxy-hydrogen and oxy-acetylene torches on the work for which each is best adapted. The purer the oxygen the better, as even small percentages of impurities decrease the economy and weaken the welds. Oxygen produced by the electrolytic process is 99 per cent. pure, the only impurity being a trace of hydrogen. The methods of generating the several gases and of regulating the pressure are described and various types of welding and cut-torches and of complete welding apparatus are also illustrated and described.

E. W. Smith¹ deals with the use of high-pressure gas for melting metals.

Thermit-Welding.—G. E. Pellissier² describes the process of thermit-welding. The chief application of this process is in welding pipe-lines for compressed air, high-pressure steam, and hydraulic pressure, where the operation has to be carried out *in situ*. As the outfit required for welding 4-inch pipes weighs less than 100 lbs. and can be manipulated in a small space, pipe-lines can be welded which would otherwise have to be provided with mechanical joints.

C. B. Auell³ describes the Benardos, Slavianoff, and Zerener processes of arc-welding. Like oxy-acetylene and oxy-hydrogen welding, all of these processes are classed as autogenous, since fusion is accomplished without pressure, simply by allowing the metals to mix and unite as they cool.

¹ *Journal of Gas Lighting*, vol. cxvi, pp. 700-701.

² *Journal of the American Society of Mechanical Engineers*, vol. xxxiv, pp. 39-49.

³ *Ibid.*, pp. 51-62.

Chains.—W. Thele¹ draws attention to the great importance of using trustworthy chains for ships' anchors.

A review is given² of the development of the chain-making industry, together with descriptions of some of the important chain-making machines.

Steel Belts for Power Transmission.—L. Silberberg³ discusses the conditions required in the design and application of steel bands for the transmission of power. The material used is a carbon steel, rough-rolled while hot, and then cold-rolled to thicknesses varying from 0·2 to 0·9 millimetre and 12 to 200 millimetres in width. By means of a hardening process the tensile strength of the finished bands is raised to 150 kilogrammes per square inch. The width of the bands for ordinary transmission purposes is 300 to 350 times the thickness, but the higher the tensile stress in working, the lower is the permissible bending stress due to passing over the pulley, and therefore the thinner the band which can be used on a given pulley diameter.

Recovery of Tin from Tinsplate Scrap.—A description has appeared⁴ of an electrolytic method for the recovery of tin from tin-sheet. The process is carried on at several works in Italy, the electrolyte being a sodium-hydroxide solution, the anodes being tin-sheet scrap and the cathodes being iron plates. The tin is dissolved in the form of sodium stannate and deposited at the cathode as metal, while the soda is regenerated. The most favourable concentration of the bath is from 10 to 12 per cent. total alkalinity, the free alkali not exceeding 7 per cent. The spongy tin is removed every twelve hours by carefully lifting the cathode and dipping it in water. This precaution is necessary to prevent the oxidation of the tin by air. After the spongy material has been completely freed from soda by careful washings, it is compressed in a small hydraulic press and afterwards melted in a furnace in sealed tubes. The product, which contains about 50 per cent. metallic tin and 50 per cent. ashes, mixed with powdered carbon, is reduced in a small open-hearth furnace.

¹ *Stahl und Eisen*, vol. xxxii. pp. 571–572.

² *Iron and Coal Trades Review*, vol. lxxxiv. pp. 523–527.

³ *Zeitschrift des Vereines deutscher Ingenieure*, vol. lv. pp. 1768–1773.

⁴ *Rassegna Mineraria*, vol. xxxvi. pp. 27–28.

PHYSICAL AND CHEMICAL PROPERTIES.

Volume Changes in Cast Iron during Cooling.—T. Turner¹ discusses the solidification of iron castings in the mould. He points out that shrinkage varies according to the size of the mould and the shape of the casting, but is generally about 0.125 inch per foot with ordinary foundry mixtures. A white iron displays the greatest amount of shrinkage, while an open grade produces a casting more nearly the size of the mould. The author defines the terms shrinkage and solidification. Shrinkage is the difference between the size of the mould and the casting when cold. He ignores the definition sometimes put forward associating shrinkage with the molten metal and contraction with the solid casting. As regards the term solidification, this to the physical chemist implies that process whereby crystals give out their latent heat of fusion, but this distinction is not necessary for practical work; solidification might be taken as that state in which the metal is cool enough to retain its form after removal from the mould. He also describes his own and Wüst's methods of measuring shrinkage. Dealing with the equilibrium diagram, the author briefly explains its application, and also describes how the dendritic structure of iron crystallisation is formed, enclosing areas of eutectic.

A. Messerschmitt² contributes an important article, in which are discussed the various changes in volume experienced by molten cast iron as it cools. At first the molten casting decreases slightly in volume, but suffers a notable increase as it solidifies, since the solid metal is less dense than the liquid at the same temperature. Shrinking now sets in, however, as the solid metal still further cools. Since the outside solidifies first, a pressure is soon set up between the solidifying and hence expanding interior and the now solid and relatively immovable exterior, with the result that in many cases the inner portion yields a solid of even denser composition than the original liquid metal. Sometimes under the influence of this pressure the molten metal presses its way out through the pores of the solid shell and the casting bleeds. As the outside shell still further cools and contracts, a new pressure is set up, but when the inner portions likewise cool and contract in their turn, cavities are produced

¹ Paper read before the British Foundrymen's Association, December 8, 1911; *Iron and Coal Trades Review*, vol. lxxxiii. p. 975.

² *Stahl und Eisen*, vol. xxxi. pp. 1579-1585.

in the metal. The author gives the results of allowing a block of cast iron, clamped at one end, to cool slowly, and shows that the higher the percentage of silicon, and therefore of graphite, the greater is the initial expansion during solidification from the molten condition, but the less is the subsequent shrinkage. The temperature of casting has an important influence on the result. If the iron is relatively cool it quickly sets in the mould and cavities are produced which weaken the casting. A very hot casting, on the other hand, takes a longer time to cool, with the result that a greater separation of graphite takes place although no cavities are formed. If this graphite separation is excessive the casting is again weakened. The best results accrue by casting at temperatures between the two extremes. Thus the tensile strengths obtained for grey cast iron with 1.78 per cent. silicon cast at various temperatures were as follows :

Casting Temperature, Degrees Centigrade.	Ten-sile Strength in Kilogrammes per Square Millimetre.
1400	15
1350	22
1245	16

Each metal has apparently an optimum casting temperature.

Cavities in casting may be avoided by allowing a sufficiently high percentage of graphite to form. High sulphur and manganese assist cavity formation by increasing the percentage shrinkage of the metal after solidification.

Volume Changes as an Indication of Strength of Cast Iron.—

It is well known that chemical analysis and the results of mechanical tests do not always indicate which material is the best for certain purposes. A. Messerschmitt¹ describes a method of testing cast iron based upon his observations, previously published,² on the alterations in volume experienced by molten cast iron as it cools down to below 400° C. The suitability of the iron for special purposes is determined upon by studying the changes undergone during cooling under well-defined conditions, and adopting those compositions and conditions which give the most suitable results for the purpose in hand.

Influence of Composition and Structure on Strength of Cast Iron.—J. J. Porter³ discusses the great difference existing in the behaviour of many brands of pig iron, which cannot apparently be accounted for on the basis of chemical composition as ordinarily determined. Dealing with the properties of coke and charcoal irons, the author states that the most noticeable difference is in the toughness or strength, which in charcoal iron is much greater, the grains having a tenacity which causes the iron to tear rather than to break off short. The difference is also noticed in the pro-

¹ *Stahl und Eisen*, vol. xxxi. pp. 1785-1790.

² *Ibid.*, pp. 1579-1585.

³ Paper read before the Pittsburg Foundrymen's Association; *Foundry Trade Journal*, vol. xiv. pp. 86-87.

perties of shrinkage, tensile strength, and depth and character of chill. With such similarity in composition as is possessed by the two materials, such differences in properties are very difficult of explanation. It is well known that charcoal iron is finer in grain than coke iron of similar composition, and that this closer grain is an almost invariable accompaniment of strong iron. It may therefore be assumed that a part at least of the differences in pig iron is due to the variations in size, shape, and arrangement of the graphite flakes. This theory is not, however, considered by the author satisfactory as an ultimate explanation. After reviewing various theories he states that perhaps the most generally accepted one is to assume the presence of variable amounts of oxygen in the metal. The most conclusive evidence is the actual isolation of magnetic oxide from samples of iron which have been badly burnt on the hearth of an air-furnace, and are known to have had the characteristics commonly attributed to oxidised metal. This theory fits in well with all that is known regarding the relation between blast-furnace practice and the properties of the iron made. While accepting this theory as probably substantially correct, the author suggests that possibly a modification of it may be still nearer the truth. It is generally assumed that the oxygen is present as dissolved oxide of iron, but it seems possible, if not probable, that it may be rather in the form of oxy-sulphide of iron, which has been shown by Campbell to be capable of existing in iron and steel at high temperatures and to possess remarkable powers of diffusion through the solid metal.

Influence of Vanadium on Cast Iron.—J. Kent Smith,¹ in dealing with the action of vanadium on cast iron, states that it is best applied in the form of the alloy ferro-vanadium. Compounded in such a way as to ensure a maximum of solubility and a correspondingly low melting-point, an alloy containing 30 to 35 per cent. of vanadium, 10 to 12 per cent. of silicon, and a little aluminium was found to give the best results in the case of cast iron, because it melted at a lower temperature than the iron. About 0.15 per cent. of vanadium should be added to the metal as it is poured into the ladle; the metal should be well rabbled to ensure thorough incorporation. The most important strengthening action of vanadium resulted from its actual presence as a constituent of certain complex carbides, which were revealed by the microscope, and which might be described as carbides of iron, manganese, and vanadium. By the addition of 0.15 per cent. of vanadium to certain cylinder iron, the tensile strength was raised from 13.4 to 14.7 tons; in another sample, using 0.2 per cent. of vanadium, the tensile strength was increased from 11.6 to 16.5 tons. Similarly the transverse tests on a fair sample of cylinder iron were improved from 2500 to 3400 lbs., while other samples were

¹ Paper read before a joint meeting of the Birmingham Branch of the British Foundrymen's Association and the Staffordshire Iron and Steel Institute, January 27, 1912; *Foundry Trade Journal*, vol. xiv. pp 144-149.

improved in varying degrees from 10 to 60 per cent. These improvements were obtained without any sacrifice of deflection.

Segregation in Castings.—G. L. Rhead,¹ in dealing with pellets and segregation in iron castings, discusses in detail the complex character of cast iron and the peculiarities of saturated solutions when solidifying. The author states that the metal in the ladle often contains less carbon at a higher temperature than is attained in melting. This points to the fact that the metal contains more carbon than it is capable of retaining at the temperature at which it is cast. Such metal might make satisfactory thin castings, provided that the separated graphite could be got rid of by a "riser" or head. Phosphorus is the most fusible constituent in iron, and consequently it lowers the melting-point of the solutions into which it enters more than any other substance present. The brittleness of phosphoric iron when cold unfits the castings for heavy machinery, and the weakness when hot may lead to fracture when cooling. In strong close-grained castings, the silicon contents of which are kept low to ensure closeness and strength, it follows that the phosphorus must be low; for great strength the maximum is 0.2 per cent. or 0.3 per cent. The relative behaviour of carbon, silicon, and phosphorus explained the vagaries observed when examining different samples of iron in which the phosphorus contents were shown by analysis to be the same. In some cases the formation of pellets was noticed, and these sometimes occurred occupying a kind of cell which they did not always completely fill; sometimes they were found loose in cavities. Analysis of the pellets showed that they contained much more phosphorus than the bulk of the metal; thus a pellet from iron with 1.9 per cent. of phosphorus contained 4.06 per cent. of phosphorus. The segregation of phosphide leads to curious results when the metal is subjected to heat; it may melt and liquefy out, or the interior of the casting may melt out.

Growth of Cast Iron.—H. C. H. Carpenter² gives the results of further research into the cause of the growth of cast iron after repeated heatings.

The Relation of Test-Pieces to Castings.—It is usual when casting to take a sample of the metal out of the ladle during the operation and determine the strength of this test-piece, and to assume that the casting itself will have the same properties. J. Treuheit³ and L. Treuheit draw attention to the fact that this is illogical, and may lead to very erroneous results. For example, the strength of a casting depends upon a variety of factors, such as

- | | |
|---------------------------|-----------------------------|
| (a) Shape. | (c) Temperature of casting. |
| (b) Chemical composition. | (d) Rate of cooling, &c. |

¹ Paper read before the British Foundrymen's Association; *Ironmonger*, vol. cxxxviii. pp. 314-315.

² Paper read before the British Foundrymen's Association, February 20, 1912.

³ *Stahl und Eisen*, vol. xxxii. pp. 514-519.

Now the test-piece can only have the same strength as the casting when all the factors are the same, and in practice this is not the case.

Influence of Shape of Test-Bars.—W. Gordon¹ and G. H. Gulliver have investigated the influence of the ratio of width to thickness upon the apparent strength and ductility of flat test-bars of soft steel. The bars were rectangular in section, having a uniform thickness of $\frac{1}{4}$ inch, but with widths varying from $\frac{1}{2}$ inch to 4 inches. Neither the elasticity nor the ultimate strength were affected by the size of section, but the ductility was found to vary considerably. For a fixed gauge-length of 8 inches the extension increased as the ratio of width to thickness varied from 2 to 7 inches. It remained sensibly constant as the ratio varied from 7 to 12 inches, and then again rose as it varied from 12 to 16 inches. The extreme difference of extension was 10 per cent., or nearly one half the extension of the narrowest bar. For a variable gauge-length equal to 11.3 times the square root of the area similar results were obtained, but the extreme difference of extension was only 2 per cent., or about one-fourteenth of the extension of the narrowest bar.

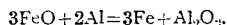
Blowholes in Steel Ingots.—K. Troubine² deals with the formation of surface blowholes in steel ingots. During the casting of a steel ingot poured from above, the interior surface of the ingot mould is frequently injured by the splashes of the metal. It is very seldom indeed that the temperatures of both the metal and the ingot mould are such that the bubbles detach themselves from the sides of the ingot mould without leaving traces. In order to avoid the formation of the surface blowholes thus formed various means have been adopted. At the Obouchoff Works the following simple arrangement has been employed: Before pouring, a truncated cone made of sheet-iron, specially strengthened in places, is lowered into the ingot mould by means of three cables which pass over a pulley and can be manipulated by hand. As the cone rises it becomes much heavier, owing to the splashes of metal which adhere to it. When it arrives at the top of the ingot mould it is either withdrawn or left on the top of the mass. The splashes which ordinarily impinge on the walls of the ingot mould are received in this cone, which, on withdrawal, will be found to be encrusted with splashes, mostly of circular shape and various sizes. These splashes are hollow, and their walls are sometimes so thin that they collapse on cooling; while others, on the other hand, are much thicker, the hollow space within representing but a small percentage of the whole volume. The method of formation of the splashes and the physical conditions underlying their formation are discussed, and it is to their formation within the ingot itself that so many of the superficial blowholes which occur during casting are due. This phenomenon is accompanied by another of somewhat doubtful nature, which

¹ *Transactions of the Royal Society of Edinburgh*, vol. xlviii. (Part I.), pp. 195-214.

² *Revue de Metallurgie, Mémoires*, vol. ix. pp. 127-132.

results from the chemical action of oxidised splashes on the molten metal, and may result in the production of blowholes due to carbon monoxide. An examination of ingots cast with this cone contrivance shows them to be free from the ordinary surface blowholes, and to possess only a few deep-seated blowholes caused by splashes of metal which have been projected above the cone. Experiments were made by allowing a cone to be in contact with the top of the metal, and in other cases by raising it a little above the upper surface of the metal, and the results are claimed to prove the contention that to these surface splashes much of the phenomenon of surface blowholes must be attributed.

Prevention of Pipe in Ingots.—C. Canaris¹ discusses the employment of thermit for the prevention of piping in ingots. This hinges on the fact that, when iron oxide and aluminium are brought into contact at temperatures above 1200° C., the latter metal combines with the oxygen, liberating metallic iron, and simultaneously raising the temperature to about 3000° C.



The thermit is kept in cylindrical sheet-iron boxes. The ingot is poured in the usual manner, and the mould allowed to remain on until a crust has begun to form on the surface of the ingot. The thermit box is now introduced and plunged to the bottom of the liquid metal. The reduction proceeds vigorously throughout the mass of metal, for the thermit iron and slag are so intensely hot that their specific gravity is appreciably less than that of the metal composing the ingot. Hence they rise rapidly to the top, and the reaction proceeds throughout the whole ingot. At the end of the reaction the level of the metal falls some 7 to 15 centimetres in the ingot. More metal is immediately added from the ladle, the mould subsequently removed, and the ingot is rolled in the usual way. In this way piping is prevented.

Segregation in Steel.—E. Heyn² and O. Bauer discuss an interesting instance of segregation occurring in a steel tube. The cross-section was studied micrographically, and exhibited a curious structure on etching with copper ammonium chloride. The outer shell of the tube remained bright, the inner portion yielding a dark coloration. Upon analysis the following results were obtained:—

	Outer Shell.	Inner Portion.
	Per Cent.	Per Cent.
Phosphorus	0·029	0·069
Sulphur	0·026	0·086

¹ *Stahl und Eisen*, vol. xxxii, pp. 303-311.

² *Ibid.*, pp. 402-403.

The interior of the tube, therefore, possessed an abnormally high sulphur and phosphorus content.

Comparison of Qualities of Basic and Acid Steel.—A comparison of the quality of acid and basic steel is instituted by W. H. Keen¹ in a criticism of a recent paper by H. Fay. The relative advantages and disadvantages of the two processes of manufacture are summarised as follows:—

FACTORS WHICH MAY LEAD TO INFERIORITY.

Acid.

1. High phosphorus.
2. High sulphur.
3. Oxide of iron, which on account of the slow reaction of the bath has to be added to hasten the removal of carbon and other elements.
4. Manganese burns out completely, so that sulphur has to be neutralised by the ferro-manganese added at almost the last moment before tapping.
5. Usually silicon is present to such an extent that it is not safe to add sufficient excess to the ladle to produce a good de-oxidising effect on the metal.

Basic.

1. Occluded slag, which is very likely to be present in larger quantity than in acid steel.
2. Oxide of iron, which has a greater tendency to form on account of the basicity of the slag, although partly eliminated by the manganese, which is always present.

FACTORS WHICH MAY LEAD TO SUPERIORITY.

Acid.

1. Oxide of iron not as likely to form, but not necessarily absent.
2. Small amount of slag necessary in the bath, and thus probably very small amounts only are likely to go into the steel.

Basic.

1. Low phosphorus.
2. Low sulphur.
3. Manganese is always present in the bath, and therefore has plenty of time to react with the sulphur, and put it into a less harmful condition.
4. Silicon burns out, so that a large amount may be added in the ladle to act as a deoxidiser.

¹ *Iron Age*, vol. lxxxviii. pp. 324-326.

Details of a series of tensile tests on steels made by both processes are also given. The prevailing opinion is that acid steel is superior to basic, but basic steel is not inferior to acid when equal care is used in the melting. A variation of 7000 lbs. in tensile strength is quite possible in two tests from the same bar as received from the mill. Knowledge of testing materials at the present time is insufficient to enable acid steel to be distinguished from basic when of identical analysis, but an empirical formula worked out by A. G. McKenna is of value in judging the merit of steel by means of the physical results, and allows predictions to be made as to limits which can be attained in elongation and tensile strength.

New Methods of Mechanical Testing.—R. Guillery¹ summarises the principal methods of testing in order to ascertain the chief physical properties of metals, which he classifies as hardness, elastic limit, elongation, and resilience, and describes and illustrates with diagrams new machines for the ball hardness test and for ascertaining elastic limit and resilience. All these methods are applied either to the finished piece or to small and cheaply obtained test-pieces. They are of little use if applied to too small a quantity of the metal to be tested. Although to this criticism it may be urged that if one of the two properties—elastic limit and resilience—be known, the third—hardness—is, in contradistinction to the tensile test, capable of revealing the homogeneity of the metal, and if the latter in its relation to hardness is proved, the probability is great that homogeneity as to elastic limit and resilience will similarly exist. Resilience is, together with the elastic limit, the most important quality to ascertain, as its test is carried out under conditions similar to those to which the metal will be subjected in practice. It is obviously a property whose value should be stated in figures within a margin of safety, and it is therefore necessary to standardise its test. It is to be regretted that the last Congress of the International Association for Testing Materials did not specify a specific type of bar, as the variation of the elongation of a steel will modify the result of the resilience test. The rate of impact should also be standardised, and it would be well if tests for elastic limit, resilience, and hardness could be rendered uniform and standard, so that they might be accepted with the results of tensile and shock tests.

High Frequency Tests of Metals.—B. Hopkinson² has experimented on the endurance of metals under alternating stresses of high frequency. The apparatus used was a high-speed fatigue tester, in which a test-piece, $\frac{1}{4}$ inch diameter and 4 inches long, was fixed vertically, the lower end being attached to heavy masses. The upper end of the piece carries a weight. The weight is attracted by an electromagnet placed above it, and excited by alternating current. The pull

¹ *Revue de Métallurgie, Mémoires*, vol. ix. pp. 471-499.

² *Proceedings of the Royal Society, Series A.*, vol. lxxvi. pp. 131-149.

thus applied varies periodically between zero and a maximum value, the frequency of the variation being twice that of the current. The test-piece behaves as a spring, the lower end of which is held fixed, while the upper end carries the weight and is free to move in a vertical direction. The adjustments are such that the natural period of vertical oscillations of this system is approximately equal to the period of the varying magnetic pull, which accordingly sets up large forced oscillations of its own period. By thus using the principle of resonance with a current frequency of 60 periods per second the range of pull applied by the magnet may be magnified from 20 to 70 times, and the stress produced in the piece can readily be made to alternate between 20 tons per square inch tension and 20 tons per square inch compression. The number of complete cycles per minute is 7200, and 1,000,000 reversals can be performed in $2\frac{1}{2}$ hours. The test-piece is fitted with a simple form of optical extensometer, whereby continuous observation can be kept of the change of length occurring in a cycle of stress. From the change of length the stress can be calculated if the piece is approximately perfectly elastic under the stress which is being applied. Endurance tests made in the new machine on mild steel showed that the steel would stand at least twenty million cycles of stress, ranging up to 29 tons per square inch. Comparative tests of the same steel, made by T. E. Stanton in a direct-stress testing machine, show that the life of a specimen, both in number of cycles and time, is not appreciably altered in increasing from 1100 to 2000 revolutions per minute, but at 7000 cycles the endurance in both respects is considerably greater. Fatigue being the cumulative effect of internal slips, the higher speed reduces the time available for the cyclical permanent set and increases endurance. Recovery, which is opposed to fatigue, is more complete at low speeds, hence endurance is also higher at low speeds. The total effect is to make the endurance fall with speed to a very flat minimum and then to rise again.

Fatigue of Welded Joints.—T. E. Stanton¹ and J. R. Pannell describe experiments undertaken with a view to obtaining a comparison of certain properties of welded joints, made by different processes and different makers, with the corresponding properties of the unwelded material from which the joints were made, and thus arriving at an estimate of the general efficiency of modern welding processes. In response to an invitation to various engineers to submit specimens of welded joints for testing, a total number of 167 joints were received. The method of welding and treatment of the joints was left entirely to the makers, the only condition imposed being that all specimens should be made from bars $1\frac{1}{4}$ inches in diameter. The joints were subjected first to a tensile test, and secondly to a fatigue test by the Wohler method, the former including determinations of the elastic limit, the yield point, the maximum stress, the total elongation, and the general and local elongations.

¹ Paper read before the Institution of Civil Engineers, December 12, 1911.

The mean result of the tensile tests on the welded joints, expressed as a percentage of the strength of the original material from which the joints were made, were:—

	Per Cent.
Hand-welded iron	89·3
Hand-welded steel	81·6
Electrically-welded iron	89·2
Electrically-welded steel	93·4

Joints made by the oxy-acetylene process were also submitted by two makers, but the results were not comparable with those obtained by the hand or electric processes. The various determinations made in the tensile tests showed a distinct want of uniformity in the material in the region of a weld, but the results of the fatigue tests proved that this does not materially affect its resistance to reversals of stress. When failure under alternating stresses of low value takes place, it is invariably due to a defect in the actual weld itself. The number of defective joints which were discovered in the whole investigation, however, leads to the broad conclusion that in important work, where the failure of any particular welded joint may involve serious damage to the structure, the subjection of each joint to a proof-load is still desirable.

Tests on Boilers.—J. E. Howard¹ gives particulars of tests carried out in order to ascertain the strain measurements of some steam boilers under hydrostatic pressures. Tests were made upon two horizontal tubular boilers which had been in service for a period of twenty-seven years. Gauged lengths were established on different parts of the boilers by means of holes, 10 inches apart and about 0·05 inch in diameter, reamed to a conical shape. The deformations of the boilers at different pressures were determined by a 10-inch micrometer strain gauge, with conical points to fit the holes laid out on the boilers. The author shows by means of diagrams the strains occurring at the region where measurements were taken; and, for the sake of comparison, stresses were computed, using a modulus of elasticity of 30,000,000 lbs.

Tests of Mild Steels.—C. E. Stromeyer² gives a detailed account of experiments on the strength of mild steels that were undertaken with a view to discovering some simple tests which could be depended upon for discriminating between good and inferior steels, it being a common experience that when a plate has failed through fracture, the usual mechanical tests to which it is then subjected hardly ever give any indication that the material was bad.

Failure of a Crank Shaft.—J. F. L. Crosland³ gives particulars of the failure of the crank shaft of a horizontal compound condensing

¹ *Journal of the American Society of Mechanical Engineers*, vol. xxxiii. pp. 1365-1403.

² Annual Memorandum to the Manchester Steam Users' Association; *Mechanical Engineer*, vol. xxviii. pp. 681-684.

³ "Vulcan," *Mechanical Engineer*, vol. xxviii. p. 636.

engine. An examination of the shaft after the fracture showed the absence of a well-rounded fillet at the corner where the projecting end, which was broken off, butted against the collar behind the crank, and it is possible that the stress set up at this part by the abrupt change of section was further intensified by an unusually tight nip of the crank web when it was shrunk on, but it is impossible to say to what extent these two causes separately contributed to the rupture.

Tests on Reinforced Concrete.—W. C. Popplewell¹ deals with the determination of the stresses in the steel and in the concrete of reinforced concrete columns. In carrying out experiments the author sought for a satisfactory method of measuring the shortening of the steel bars and the simultaneous shortening of the adjacent concrete under the loads applied to reinforced columns. From these measurements, if they were reliable, he thought it would be possible to calculate the stresses in the steel and concrete, when the elastic moduli for the two materials were known. It was also thought that measurements made in this way would be the means of revealing any movement of the steel relatively to the concrete. The main experiments were carried out on five columns, 6 inches square, each reinforced by four round steel bars $\frac{3}{4}$ inch in diameter. Loads were applied in a testing machine, and corresponding shortenings of the steel and concrete were measured by means of Martens' extensometers. For the steel these were applied to the ends of pairs of pins projecting from the reinforcing bars through holes in the concrete, and for the concrete they were applied to the surface as near as possible to the steel.

Besides the main experiments, others were carried out to compare the effect of loading when the load was uniformly distributed over the end of the column and when it was applied in the centre. This enabled a comparison to be made between the effect of having the load transmitted directly to the ends of the bars, and having it communicated to the bars through the holding grip of the concrete. The result showed practically no difference. The experiments to find out the value of the modulus of the steel and the concrete yielded values respectively of 30,200,000 lbs. and 1,535,000 lbs. per square inch.

A further set of experiments carried out to determine the intensity of the frictional grip of the concrete on the steel resulted in values ranging from 300 to 600 lbs. per square inch of bar surface, to cause slipping. The stresses in the steel and concrete, calculated for a working load of $13\frac{1}{2}$ tons which the columns were designed to carry, were found to be, respectively, 437 lbs. and 8650 lbs. per square inch. This gives a load on each bar of 1.7 tons, and comparing this with the load required to push one of the bars through the concrete, as found from the experiments on frictional grip, it is evident that from this point of view there could not have been any slipping of the steel in the concrete.

¹ Paper read before the Institution of Civil Engineers, January 9, 1912.

Tests on Steel Columns with Concrete Filling.—W. H. Burr¹ investigates the effect of a concrete filling on increasing the carrying capacity of a steel column. The columns tested consisted first of two types of built-up columns of plain steel, and secondly of exactly similar steel members filled with concrete. The reinforced concrete columns were filled with 1:2:4 concrete, and were tested at three months. The steelwork consisted in one case of four vertical steel angle-bars arranged as the four corners of a square and braced together with lattice bars to form a square column $6\frac{3}{8}$ inches in exterior dimensions, and in the second case of four vertical channels arranged with their flats forming four opposite sides of an octagon, and wrapped at intervals with batten plates bent round in the form of an octagon $7\frac{1}{2}$ inches across the flats. Only the concrete lying within the exterior dimensions of the steelwork was included in the calculations. All the columns were 7 feet long. Four of each type were tested, two filled with concrete and two without concrete. The plain steel columns withstood an average total load of 67 tons on an area of 4 square inches in the case of the angle construction before failure, and of 68 tons on an area of 4.76 square inches in the channel construction, which was not so securely braced. The addition of concrete increased the maximum loads before failure to an average of 98 tons on a total combined area of 42.25 square inches in the angle reinforcement, and to 96 tons and 112 tons respectively on an area of 49.75 square inches for the two channel-bar columns.

Reinforcements of Concrete with Cast Iron.—E. von Emperger² suggests that cast iron may be used like steel for strengthening concrete, for the concrete greatly enhances the strength of the metal. The results recorded in the table show the effect of surrounding three cast-iron pipes with cement of different kinds, all four pipes being originally equal in strength.

Pipe No.	Treatment.	Breaking Strength, Tons.
1	.....	137
2	} Surrounded by cement 29 centimetres in thickness . . }	315
3		307
4		342

Other experiments confirm the above, and it is evident that a wide field for research is hereby opened up for structural engineers.

Definition of "Elastic Limit" and "Yield Point."—In a report issued by the Engineering Standards Committee³ the following defini-

¹ Paper read before the Institution of Civil Engineers, January 9, 1912.

² *Stahl und Eisen*, vol. xxxii. pp. 355-356.

³ Report No. 56, London, 1911.

tions of the terms "elastic limit" and "yield point" are given. The elastic limit is the point at which the extensions cease to be proportional to the loads. In a stress-strain diagram plotted to a large scale it is the point where the diagram ceases to be a straight line and becomes curved. It can only be determined by the use of very delicate instruments, and by the measurements of the extensions for small successive increments of load. It is impossible to determine it in ordinary commercial testing. The yield point is the point where the extension of the bar increases without increase of load. A practical definition would be that it is the load per square inch at which a distinctly visible increase occurs in the distance between gauge points on the test-piece, observed by using dividers; or at which, when the load is increased at a moderately fast rate, there is a distinct drop of the testing-machine lever, or, in hydraulic machines, of the gauge finger. A steel test-piece at the yield point takes rapidly a large increase of extension, amounting to more than $\frac{1}{200}$ th of the gauge length. The point is strongly marked in a stress-strain diagram.

Determination of Stresses in Materials.—In a lecture before the Sheffield Society of Engineers and Metallurgists, E. G. Coker¹ discussed the use of polarised light as an aid to determining stresses in engineering materials. He pointed out that many of the problems with which engineers were called upon to deal related to stresses which varied enormously over a comparatively small distance, and it was therefore necessary to have a method of dealing with stresses at a point. This was done by the optical method of determination. By certain principles which had long been known, the stresses in a transparent material could be ascertained, and if it could be shown that the stress distribution in a transparent body for some case, or a certain number of cases, was precisely the same—or very nearly the same—as in metals—then the use of the optical method for determining stresses in bodies of any given form was quite justified.

Modulus of Elasticity and Thermal Expansion of Metals.—H. Sieglerschmidt² shows that the relationship between the elastic and thermal properties of a large number of metals can be expressed by means of the equation $E/s = C(1/A\beta)^n$, in which E is the elastic modulus, s the density, A the atomic weight, β the coefficient of thermal expansion, and C and n are constants.

Changes in Dimensions of Steel Wire when Twisted.—J. H. Poynting³ describes experiments on the changes in dimensions of a steel wire when twisted, and on the pressure of distortional waves in steels. The author has previously shown⁴ that when a loaded wire is twisted it lengthens by an amount proportional to the square of the

¹ *Mechanical Engineer*, vol. xxviii. p. 741.

² *Annalen der Physik*, vol. xxxv. pp. 775-782.

³ *Proceedings of the Royal Society*, Series A., vol. lxxxvi. pp. 534-561.

⁴ *Ibid.*, vol. lxxxii. pp. 546-559.

angle of twist. He now shows that if the wire is previously straightened by heating it under tension, the lengthening is, within errors of measurement, the same for all loads which could be applied, so that, as was supposed, the only function of the load in the earlier experiments is to straighten the wire. A theory of the changes in dimensions is given, which appears to account for the experimental results when a single wire is dealt with.

Calibration of Testing Machines.—A. Martens¹ states that for the calibration of testing machines a set of high-grade cylindrical steel specimens have been prepared at the Royal Testing Institute, Gross-Lichterfelde, calibrated for loads up to 500 tons. Further, the author has devised a machine capable of measuring forces up to 3000 tons per square inch, which depends for its action on the hydraulic principle, thus obviating the difficulty encountered in the damaging of the beams of testing machines by the heavy stresses at fracture of test-pieces under great loads.

Electric Testing Machine.—K. Perlewitz² describes an electric machine designed by G. Kapp for testing the capacity of steel and other structural material to withstand frequent stress repetitions. One end of the test-bar is attached to a rigid block and the other to an armature, placed immediately over the poles of two electromagnets, excited by the same alternating current. The test-piece can be subjected to about fifty pulls per second, and the stress can be varied by varying the amount of current. It can also be made alternating by duplicating the magnets and using two-phase current. With a current of 110 volts, a pull of about 4 cwts. can be obtained, and it is possible to make ten million applications of the test-stress within thirty hours.

Influence of Rate of Shock.—J. Resal³ discusses the theoretical considerations involved in shock tests, with special reference to the influence of the speed at which the shock is delivered and transmitted throughout the bar. He gives mathematical formulæ, showing that there is a critical rate of propagation which leads to fracture and will consequently entail dangerous conditions. Reference is made to the investigations of Henry on the same subject.

The Aphegraph.—R. Guillery⁴ describes the application of the aphegraph to shock-testing machines. It is a simple device consisting of a crank and shaft, which can be applied to alternating stress machines in order to record the speed and acceleration of the piston. It is exceedingly simple in design, and can be employed to shorten the

¹ *Preussische Akademie der Wissenschaften* (Berlin), Report No. 53, 1911, pp. 1132-1141.

² *Elektrotechnische Zeitschrift*, vol. xxxii. p. 858.

³ *Revue de Métallurgie, Mémoires*, vol. viii. pp. 741-747.

⁴ *Mémoires de la Société des Ingénieurs Civils de France*, 1911, Part II., pp. 143-158.

labour of calculation in shock tests with a falling weight, and for many other purposes. The appliance is the invention of Charpentier, who described it in May 1911 before the French Academy of Sciences.

Testing Machines.—C. A. M. Smith¹ describes the arrangement of various types of testing machines, including the Wicksteed, Kennedy, Amsler, and Riehle types.

A. Seydel² describes a testing machine for testing up to 3000 tons.

Brinell Hardness Numbers.—A table of Brinell hardness numerals is given.³

Strength of Materials.—E. Leber⁴ discusses the advances made during the last ten years in our knowledge concerning iron, particularly as regards the influence of alloying elements, upon its chemical and mechanical properties and the methods of testing the last named.

R. T. Stewart⁵ investigates the strength of steel tubes, pipes, and cylinders under internal-fluid pressure.

Expansion of Nickel Steel.—C. E. Guillaume⁶ deals with the changes in volume which nickel steels undergo in the course of time and when heated. Steels with from 28 to 42 per cent. of nickel expand slowly, while steels containing from 42 to 70 per cent. of nickel contract. Nickel steels of still higher grades remain unchanged. A steel containing 36 per cent. of nickel expanded in 4500 days by 38μ , but the extension of a hardened nickel steel of the same composition was only 15μ . In forged invar bars of 36 per cent. nickel slow-heating up to 150°C ., followed by slow-cooling to 40°C ., accelerates the transformation, and the bars are subsequently much more constant as to length than similar bars kept at ordinary temperature. In general, nickel steels should be heated up to 100°C . for many hours to hasten the ageing; this applies also to the drawn and quenched alloy. Two causes appear to be at work, the one favouring slow expansion, the other slow contraction. In the 42 per cent. alloy the two effects balance one another, and these alloys are also less subject to oxidation than other steels. The correct length of nickel-steel bars which have undergone various thermal and mechanical treatments can be calculated by means of tables which are given.

Use of Nickel-steel Rails.—Some experiments on the wear of rails of different compositions have been conducted⁷ by the New York State Railways at Rochester, N.J. In the spring of 1909 a section of

¹ *Cassier's Magazine*, vol. xli. pp. 157–163.

² *Stahl und Eisen*, vol. xxxii. pp. 399–402.

³ *American Machinist*, vol. xxxv. p. 986.

⁴ *Stahl und Eisen*, vol. xxxii. pp. 129–135, 350–355, 526–533, 695–700 *et seq.*

⁵ *Journal of the American Society of Mechanical Engineers*, vol. xxxiv. pp. 495–510.

⁶ *Comptes Rendus*, vol. cliii. p. 156.

⁷ *Electric Railway Journal*, vol. xxxviii. p. 801.

double track about 800 feet long was laid with 7-inch 100-lb. rails containing 3 per cent. of nickel. The rails maintained so good a surface that in the summer of 1911, 150 tons more of the same rail were used, the new section being jointed with nickel-steel fishplates, bolts, and nuts. Another section of track has been laid with high-carbon 7-inch rails with carbon ranging from 0.75 to 0.875 per cent. It is thought that such rails will be strong enough structurally to sustain the heaviest service conditions which can be imposed upon them by electric-railway service, and that they can be handled and laid without risk of breakage if proper care is taken. For the remainder of the new track titanium rails are being used, which have been the company's standard for some time; a 5-inch titanium rail is employed, and 1500 tons of these have been laid in 1911.

Wear of High-silicon Tramway Rails.—R. B. Holt¹ considers that much irregular wear of rails and tires would be prevented if the rail surface were made convex to begin with. The wear of modern high-carbon tram rails manufactured to standard specification is very irregular, much more so than the wear of the earlier low-carbon rails wrongly described as soft, but actually attaining a considerable percentage of manganese which gives excellent wearing results. In Leeds remarkable results have been obtained from using Sandberg silicon steel rails, over 6000 tons having been used during the past four years. These steel rails, as compared with ordinary basic Bessemer rails, show a reduction of wear of 33 to 40 per cent. Sandberg's steel rails are not free from the corrugation effects, but such markings do not develop as rapidly as in ordinary steel, and after four years' service it has not yet been necessary to grind the corrugations from the Sandberg steel rails in Leeds. The thermit-welded joint has given satisfactory results on the Leeds tramway tracks, 11,000 joints having been welded during the past eight years, and the total breakages not exceeding 3 per cent.

Wear of Rails, and Rail Failures.—Investigations have been carried out by the Railway Committee of the American Railway Engineering Association upon the causes of rail failures, and records of such failures have been compiled, the results being presented in a recent report.² The report contains a number of statistical diagrams, together with information as to results with rails of different steels, sections, and weights. The relation of phosphorus to carbon prescribed for the rails under investigation was as follows:—

Phosphorus per Cent.	Carbon per Cent.
0.10	0.43 to 0.58
0.085	0.55 to 0.65
0.06	0.55 to 0.68
0.04	0.63 to 0.76
0.03	0.70 to 0.85

¹ Report to the Municipal Tramways Association, *Electrician*, vol. lxxviii, pp. 9-10.

² Bulletin No. 137 (July 1911), American Railway Engineering Association, Chicago; *Engineering News*, vol. lxxvii, pp. 538-539.

A comparison of rails of Bessemer and open-hearth steel indicates very emphatically the superiority of the latter kind of steel.

With regard to the proportion of discard of the ingot, the Committee remarks that the marking of the rails to distinguish the original position of the material in the ingot has become very general. The failures of rails from near the head of the ingot are the most numerous, but there are also very many failures in the next following two-fifths of the height of the ingot. Unless there is an improvement in the making of the ingots, it will require the entire elimination of the upper two-fifths to be sure of obtaining only sound rails. Several companies are making trials of experimental lots of special Bessemer and open-hearth steel alloyed with different metals, such as titanium, nickel, chromium-nickel, &c., but the results have not always been satisfactory. The average number of failures per 10,000 tons of the different kinds of rail tested are: Open-hearth steel with titanium, 12; Bessemer steel with titanium, $13\frac{1}{2}$; Bessemer steel with nickel, 96; open-hearth steel with chromium-nickel, 640. On the Central Railway of New Jersey the record for 90-lb. open-hearth chromium-nickel rails was very bad, there having been 1129 failures per 10,000 tons of rail laid. On the Baltimore and Ohio Railway with the same class of rail there were 595 failures per 10,000 tons. The amount of nickel is 2 to $2\frac{1}{2}$ per cent. and the chromium 0.5 to 0.9 per cent. On another railway 85-lb. manganese-steel rails were compared with ordinary Bessemer, and in nineteen months the percentage of area of head abraded was slightly over three times as much for the Bessemer as for the manganese. The manganese rail contained 9.93 per cent. of manganese. In another case, 85-lb. manganese rails were compared with ferro-titanium steel, and in eight months the ferro-titanium rail showed over twice as much wear as the manganese.

The report by J. E. Howard, who was appointed by the Interstate Commerce Commission and the Bureau of Standards of the United States to inquire into the cause of the Lehigh Valley railroad accident, which occurred on August 25, 1911, is published.¹ He has made an exhaustive examination of the fractured steel rail which was the apparent cause of the disaster, and points out that current railroad practice in the use of hard-steel rails and high-wheel pressures has almost reached the limit of endurance of the metal.

J. Grierson² suggests that experiments might with advantage be made in the use of alloy steels for tramway rails, with a view to establishing a standard composition capable of resisting the heavy wear due to the conditions of electric traction. Manganese steel is chiefly used for points and crossings, but there are a few tramway systems where cast steel is used in conjunction with iron-bound crossings in preference to manganese steel. The author favours the latter material, owing to the fact that the majority using manganese steel admit its liability to honeycomb. Thermit welding is used on eighteen

¹ *Iron Trade Review*, vol. 1, pp. 353-359.

² Report to the Municipal Tramways Association; *Electrician*, vol. lxxviii, pp. 6-8.

systems, but experience shows that sooner or later all thermit-welded joints become dished. In Glasgow, in the centre of the city, where traffic is heaviest, the number of broken joints has been enormous, the life of a joint averaging about three years, at which rate all welded joints will have been cut out long before the rails become worn out.

H. Mattinson¹ considers that the composition of the steel for tramway rails, as prescribed by the British Standard Specification, is such that it cannot be classed as high-quality steel, and is not of a grade suitable for electric traction. In his experience the thermit-welded joint has proved more successful than other types, since during a period of five years less than 3 per cent. of breakages occurred with 7000 joints. The dishing of the rail at the joint is a serious defect, and a method is now coming into use of welding into the dished rail hard steel by means of the oxy-acetylene blowpipe.

Wear of Tires.—In order to reduce the wear of the tread and flange of tires a system of lubrication of the side of the head of the rail has been tried on some railways in America.² It is stated that water sprayed on to driving-wheels of passenger engines has increased the period between the re-turning by three or four times. If solid lubricants or oil are used there need be no risk of application of the lubricant to the tread. Several hundreds of engines in the United States have been equipped with lubricating appliances, among which the most efficient is said to be the Elliot flange lubricator. The time between re-turning has increased in some instances from three to twenty months, and in other instances, measured in mileage, the improvement is from 25,000 to 75,000 miles.

B. Schwarze³ discusses the manner in which metal tires of locomotive and carriage wheels wear away during service, and the best means of testing the tires before use.

An adverse criticism is given⁴ of B. Schwarze's researches on the hardness of steel tires.

Tests of Rails.—C. Fremont⁵ describes his method of testing rails. His impact test is performed on specimens measuring $10 \times 8 \times 30$ millimetres, supported on knife edges 21 millimetres apart, and they receive the impact of a weight of 10 kilogrammes falling from a height of 4 metres. The material is considered dangerously brittle if the energy required to produce fracture is less than 20 kilogramme-metres. Tests made on a whole-rail section cut up into forty-one pieces show that the material from the web and centre of the head is brittle, while the remainder may be quite satisfactory. Fremont's new test consists in removing the material from the head of the rail

¹ Report to the Municipal Tramways Association; *Electrician*, vol. lxxviii. pp. 8-9.

² *Engineering*, vol. xcii. pp. 636-637.

³ *Stahl und Eisen*, vol. xxxi. pp. 2046-2047.

⁴ *Ibid.*, vol. xxxii. pp. 473-477.

⁵ *Génie Civil*, vol. lix. pp. 7-11, 26-30, 48-51, 72-76.

to a depth of 20 millimetres. This exposes the brittle material, and an 18-inch length of rail is then tested in a machine of the flywheel type in such a manner that the brittle material is under tension when it receives the impact.

Hardness Tests of Rails.—Some experiments have been carried out in the laboratory of the Italian State Railways on annealed rails, which displayed when in use great variations in hardness. The experiments have shown that there is a relation between the hardness as determined by static methods and the coefficient of resistance to tensile stress. A method of applying the hardness test so as to bring out this relation, and incidentally to ascertain the tensile strength of the material, is described¹ and illustrated.

Corrugation of Rails.—G. E. Pellissier² suggests a new theory of the cause of rail corrugation. He considers that corrugations are directly due to non-uniformity of pressure between the tread of the car wheel and the surface of the rail, and between the flange of the wheel and side of the rail head; that any set of conditions which produces this non-uniformity of pressure will cause corrugations if the maximum intensity of pressure exceeds the elastic limit of the rail material, but comparatively few combinations of circumstances produce this condition. Any conditions which displace the position of a point of maximum intensity of pressure from the approximate centre of the rail head to the edge where particles are free to move in one or more directions reduce the elastic limit to its linear value, which is not more than one-third of its cubical value. The relative position and shape of the rail-head, wheel-tread, and wheel-flange have great influence on the position of the point of maximum pressure, and thus are mainly responsible for the corrugations; if the rail and wheel are so designed, and the rails so laid that the maximum intensity of pressure occurs near the centre of the tread surface of the rail, most of the corrugations can be eliminated. Corrugations produced by pressures exceeding the cubical elastic limit of the steel can be eliminated only by raising the elastic limit, increasing the area of contact, or by making the acceleration so uniform that a uniform cold-flowing of the metal will follow. In support of this theory a few facts regarding the intensity of pressure and its point of application are given.

K. Sieber³ discusses the various causes and occurrences of corrugations which frequently occur on well-used railway lines. It is observed that they do not appear on sharp curves, and only occur in other cases when the speed of the traffic exceeds a certain limit.

Specifications for Iron and Steel.—H. B. Strange⁴ deals with specifications for steel under the following heads: (1) Unwritten

¹ *Ingeniero Ferrovia*, vol. vii. No. 12; *Revue de Métallurgie, Extraits*, vol. viii. pp. 719-720.

² *Electric Railway Journal*, September 30, 1911; *Electrician*, vol. lxxviii. p. 221.

³ *Stahl und Eisen*, vol. xxxi. pp. 1474-1475.

⁴ Lecture delivered before the Junior Institution of Engineers; *Mechanical Engineer*, vol. xxviii. pp. 774-776.

specifications, that is, those which are the result of long commercial intercourse between manufacturer and user, which may be taken to include crucible steel; (2) specifications prepared by the Admiralty and War Office governing the manufacture of forging and castings for guns; (3) specifications prepared by the Admiralty, Lloyd's Register, Bureau Veritas, &c., for shipbuilding; (4) specifications prepared by railway companies; (5) specifications issued by large engineering firms; and (6) miscellaneous specifications for steel for special purposes prepared by private individuals.

New standard specifications for engine bolt iron, locomotive-boiler rivet steel, open-hearth steel girders and high tee rails, wrought-iron bars, and rolled-steel axles, and the revised standard specifications for steel castings issued by the American Society for Testing Materials, have been published.¹

Specifications for Steel Axles and Shafts.—The American Society for Testing Materials has issued² specifications relating to steel axles and shafts. The chemical composition specified is as follows:—

Carbon	Not over 0·60 per cent.
Manganese	0·40 to 0·80 "
Phosphorus	Not over 0·05 "
Sulphur	Not over 0·05 "

The physical tests to which the material is required to conform are as follows:—

Ultimate strength, lbs. per square inch	85,000
Elastic limit, lbs. per square inch	50,000
Elongation in 2 inches per cent. . . .	22
Reduction of area, per cent. . . .	45

The following regulations as to heat treatment have been laid down:—

Each axle, shaft, or similar part shall be allowed to cool after forging, shall then be re-heated to the proper temperature, quenched in some medium, allowed to cool, and then re-heated to the proper temperature for annealing.

Warped axles or shafts or similar parts must be straightened hot at a temperature above 900° F.

All axles, shafts, and similar parts shall be free from cracks, flaws, seams, or other injurious imperfections when finished.

All axles, shafts, and similar parts must be rough-turned, with an allowance of $\frac{1}{8}$ inch on surface for finishing, except on collar, which is to be left rough-forged.

The heat number shall be stamped on the rough-forged collar.

Specifications for Steel Reinforcement Bars.—The proposed specifications drawn up by W. R. Webster for submission to the

¹ *Iron Trade Review*, vol. 1. pp. 762-765.

² *Iron Age*, vol. lxxxviii. p. 425.

American Society for Testing Materials have appeared.¹ The chemical and physical properties are as follows:—

Properties Considered.	Structural Steel Grade.		Hard Grade. ¹		Cold-twisted Bars.
	Plain Bars.	Deformed Bars.	Plain Bars.	Deformed Bars.	
Phosphorus, max.—					
Bessemer	0·10	0·10	0·10	0·10	0·10
Open-hearth	0·05	0·05	0·05	0·05	0·05
Ult. tensile strength, lbs. per sq. in.	55,000 to 70,000	55,000 to 70,000	80,000 min.	80,000 min.	{ Recorded only
Yield point, min., lbs. per sq. in.	33,000	33,000	50,000	50,000	55,000
Elongation, min. per cent. in 8 ins.	1,400,000 tens. str.	1,250,000 tens. str.	1,200,000 tens. str.	1,000,000 tens. str.	5 per cent.
Cold bend without fracture—					
Bars under $\frac{3}{4}$ in. in diameter, or thickness	180° d.=1 t. 180° d.=1 t. 180° d.=3 t. 180° d.=4 t. 180° d.=2 t.				
Bars $\frac{3}{4}$ in. in diameter or thickness and over	180° d.=1 t. 180° d.=2 t. 90° d.=3 t. 90° d.=4 t. 180° d.=3 t.				

¹ The hard grade will be used only when specified.

Specifications for Motor-car Steels.—At a meeting of the American Association for Testing Materials a proposed standard specification was submitted covering motor-car carbon and alloy steels. It comprises eight classes, according to chemical composition, details of which are given.²

Magnetic Properties of Special Steels.—O. Boudouard³ has determined the resistance of nickel, manganese, chromium, and tungsten steels by means of the Kelvin method. Two series of alloys with each metal were prepared, in one of which the percentage of carbon was from 0·1 to 0·2 per cent., and in the other from 0·8 to 0·9 per cent. The author found that in carbon steels the electrical resistance increases with the carbon. With nickel constant the resistance is considerably increased by the carbon, but carbon appears to have very little effect on manganese steels. In the chromium series irregularities were observed which appeared to have no relation to the carbon percentage. In the case of tungsten steels the state of the metal, whether hard, annealed, or normal, appeared to have no influence on the resistance.

O. Boudouard⁴ has continued his investigations of the electrical resistance of steels, which, in the first instance, were confined to

¹ *Iron Age*, vol. lxxxviii. p. 379.

² *Iron and Coal Trades Review*, vol. lxxxiv. p. 609.

³ *Comptes Rendus*, vol. cliii. pp. 1475-1478.

⁴ *Revue de Metallurgie, Mémoires*, vol. ix. pp. 294-303.

carbon steels, and a few chromium, tungsten, manganese, and nickel steels containing small percentages of the alloy metal,¹ and to a series of special steels in which the percentage of the alloy metal rises as high as 30 per cent. Tables are given showing the results of the experiments. Benedicks' formula enables the specific influence of each metal on the electrical resistance of special steels to be ascertained. Generally speaking, the increase in the resistance per unit of the added metal gradually decreases.

C. F. Burgess² and J. Aston have determined the electrical resistance of electrolytic iron and its alloys, the mechanical and magnetic properties of which have been previously studied. Alloys with high values for physical hardness and magnetic coercive force show also high electrical resistance. The most resistant alloys are those containing nickel and chromium, with or without silicon, carbon, or vanadium. A table is given showing the composition and electrical resistance of those alloys having a resistance more than seven times greater than that of standard electrolytic iron.

J. G. Gray³ and A. D. Ross describe their experiments on the magnetic properties of a variety of special steels at low temperatures. The experiments were carried out on specimens of steels prepared by Sir W. G. Armstrong, Whitworth & Co., from the same variety of soft iron, in the form of cylindrical rods. The specimens, which included iron, carbon steels, chrome steels, silicon steels, phosphorus and tungsten steels, were tested at room temperature and at -190°C . (when immersed in liquid air) in the conditions brought out by (1) normalising, (2) annealing at 900°C ., (3) quenching at 450°C ., and (4) quenching at 900°C . It was found that the effect of cooling to the temperature of liquid air is in general to diminish the permeability for low values of the magnetising force, and to increase it for high values. A magnetisation curve corresponding to -190°C . lies initially below and finally above that corresponding to room temperature. In the carbon steels the value of the field strength for which the curves cross increases with the carbon content. In these steels the coercive force is greater at -190°C . than at 15°C . In high carbon steel in the quenched condition the coercive force is 32 at room temperature; at -190°C . it is 50. In the case of chrome steels the crossing points of the curves are very low. In annealed steel of this variety containing 10 per cent. of chromium the crossing point is at $H=8$, and is only slightly higher in the condition brought about by quenching at 450°C . In this steel cooling to -190°C . brings about an increase in coercive force. In annealed steel containing 4 per cent. of chromium crossing of the curves takes place for $H=150$. In the condition brought about by quenching at 450°C . crossing takes place at $H=16$. Quenching at 900°C . results in the magnetising force necessary to bring about crossing becoming very great. In annealed silicon steels containing 3.5 per cent. of silicon,

¹ *Journal of the Iron and Steel Institute*, 1903, No. I. p. 299.

² *Transactions of the American Electro-Chemical Society*, vol. xx. pp. 205-224.

³ Paper read before the Faraday Society, April 23, 1912.

crossing of the curves occurs for $H = 150$ c.g.s. units. After quenching at 900°C. the magnetisation curve corresponding to -900°C. lies everywhere above that corresponding to room temperature. An annealed-steel specimen containing 6 per cent. of silicon behaved in a somewhat similar manner. In the annealed condition crossing of the curves took place for $H = 180$ c.g.s. units. After quenching at 900°C. crossing took place for $H = 15$ c.g.s. units. In the silicon steels the effect of the liquid-air temperature is to increase the coercive force. Specimens of tungsten and phosphoric steels behaved quite normally. Tungsten steel is magnetically much harder at -190°C. than at ordinary room temperature. In all cases where a series of special steels has been examined the general rule is found to hold that the crossing point of the $I-H$ curves, corresponding to 15°C. and -190°C. respectively, is higher the greater the amount of the added element—carbon, silicon, chromium, and others. This rule holds for the steels in either normalised, annealed, or quenched conditions.

Permeability of Iron.—E. F. W. Alexanderson¹ shows by means of tests carried out on a high-frequency machine that iron is able to follow as high a frequency as 200,000 cycles per second, and that its magnetic permeability under high frequency is probably the same as with low frequency. He concludes from the experiments that the amount of iron used in the construction of high-frequency motors might be reduced with advantage.

Magnetic Properties of Nickel and Iron.—In order to ascertain the influence of the magnetic field on passive nickel and iron, H. G. Byers² and A. F. Morgan placed an anode of nickel or iron and a platinum cathode in a test-tube containing an electrolyte (sulphuric or nitric acid, sodium nitrate, or potassium sulphate), and measured the current density required to render the anode passive, both under ordinary conditions and when the test-tube was placed between the poles of an electro magnet. The current density required to render nickel passive was found to increase materially when the metal was in the magnetic field, and the same result holds good for iron. Steel is more difficult to render passive when magnetised, and soft steel is affected to a greater extent than hard steel. The positive pole of the magnetised piece of metal is more easily rendered passive than the negative pole.

Magnetic Properties of Metal Compounds.—E. Wedekind³ states that the magnetisability of simple chemical compounds, which are derived from a ferro-magnetic or a latent-magnetic metal, is a well-defined molecular property, which is associated with the stoichiometric composition or constitution of the compound. Simple

¹ *Elektrotechnische Zeitschrift*, vol. xxxii, pp. 1078-1081.

² *Journal of the American Chemical Society*, vol. xxxiii, pp. 1757-1761.

³ Paper read before the Faraday Society, April 23, 1912.

compounds of ferro-magnetic metals are throughout essentially more feebly magnetic than are the metals themselves, so far as it concerns independent representation of the degree of valency. Simple compounds of the latent-magnetic metals—manganese, chromium, vanadium, and probably also titanium—are generally more strongly magnetic than the metals; the maximum magnetisability is nevertheless determined by the stoichiometric composition, especially where several compounds of the same components exist. Manganese has a maximum in the trivalent condition when combined with such elements as can themselves be trivalent, that is, when the atomic ratio is 1 : 1. Some of these compounds act as permanent magnets. With the independent oxides of manganese, chromium, and vanadium, the susceptibility appears as a function of the metal content, with the sulphides of vanadium as a linear function of the sulphur content; it is thus dependent on the valency of the metal in the respective compound. So-called mixed oxides or sulphides, which represent no single degree of valency, are for the total metals more strongly magnetic than the independent forms of compound; this is connected with the acid nature of one of the components which always exhibits the higher degree of valency. Such a compound always reveals itself when graphically represented by a sharp break in the curve. The magnetisability generally falls off with a lowering of the atomic weight of the principal metal; several manganese compounds are ferro-magnetic. No vanadium compound is decidedly ferro-magnetic. To the left of vanadium stands titanium and its compounds, the investigation of which is now in hand, and with this element the minimum will be reached.

E. Wedekind¹ and T. Veit describe the following further ferro-magnetic compounds of manganese: manganese bisulphide, manganese selenide, manganese silicide, and manganese arsenide.

Steel for Permanent Magnets.—E. Kilburn Scott² discusses steel for permanent magnets, and describes the experiments of C. F. Burgess and J. Aston.

Nomenclature of Microscopic Constituents.—H. M. Howe³ deals with the need for uniformity in the nomenclature of the microscopic constituents of iron and steel. The convenience of readers requires that the meanings of words should be changed as little as possible unless for strong reasons, and it would therefore be wise to disturb the existing nomenclature as little as possible. Most of the present names have been in general use for nearly a quarter of a century, and to attempt to forbid their use would be as unwise as it would be futile.

¹ *Berichte*, vol. xlv. pp. 2663–2670.

² *Iron and Coal Trades Review*, vol. lxxxiv. p. 377.

³ *Metallurgical and Chemical Engineering*, vol. x. pp. 23–26.

Appliances for Metallography.—C. R. Hayward¹ describes several appliances for use in the metallographical laboratory of the Massachusetts Institute of Technology. One is an electric-resistance furnace, by which accurate control of the heat necessary for metallographic work is obtained. A grinding and polishing machine is also described, in which the specimen is held against a horizontal plane instead of against a vertical wheel, as is usual in such machines. In order to obtain good results in making photomicrographs the surface of the specimen must be perpendicular to the axis of the microscope, and various devices for securing this need have been proposed from time to time. A new form of specimen-mounter is described, which gives excellent results as an accessory to a vertical microscope, as it can be quickly adjusted to take specimens of different sizes.

H. Le Chatelier² and W. Broniewski describe an automatic photographic recorder, which can most advantageously be employed in researches on the critical points, as it gives a continuous curve in which are clearly shown critical points which are too weak to be perceived by the interpolation of a thermocouple. A summary of previous experiments in the direction of automatic registration is given, after which a special apparatus is described and illustrated. It is based on a principle proposed by Saladin, who used a prism inclined at an angle of 45° between two galvanometers, with the result that the deviation of the ray reflected on the mirror of the first galvanometer was transformed vertically, while the new reflection on the mirror of the second galvanometer was deflected horizontally. The appliance described eliminates several sources of error, such as those due to the contacts being maintained at a constant temperature, and to the fact that being outside the furnace they are not influenced by the molecular transformation that may occur in the centre of the bars.

A. Sauveur³ describes a perfected microscope for the examination of metals, termed a universal metaloscope. The instrument allows of the examination of large as well as of small specimens with equal ease and accuracy, while the problem of proper support for iron and steel specimens of all sizes and shapes has been solved by the provision of an electro-magnetic stage, which can be connected with any suitable current supplied, and by means of which large specimens may be firmly held in an accurate position.

Crystalline Structure of Metals.—C. H. Desch⁴ describes the various methods adopted for the purpose of isolating and studying metallic crystals. Only in a few cases were the individuals thus obtained bounded by plane faces, and the dendritic forms, or crystal skeletons, usually observed were not readily brought into correspond-

¹ *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 973-979.

² *Revue de Métallurgie, Mémoires*, vol. ix. pp. 133-146.

³ *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 961-971.

⁴ Paper read before the Royal Philosophical Society of Glasgow, November 29, 1911; *Mechanical Engineer*, vol. xxviii. p. 699.

ence with the geometrical laws of crystallography. The nearest analogies of these crystal skeletons were the forms assumed by ice and snow crystals and the inclusions found in certain blast-furnace slags, in pitch-stone, and other rocks. The study of crystal skeletons was complicated by growth in three dimensions, and in such cases as those of ordinary metals and alloys a suitable method of examination was by grinding parallel faces on a specimen, photographing a marked area, and grinding off successive thin layers: photographing the same area after each operation. The crystallite, of which plane sections had been thus obtained, might now be built up in plasticine, and an idea of its solid structure thus obtained. Crystallites must be considered as imperfect or undeveloped crystals, and they were, as a rule, characterised by the absence of sharp angles on plane faces. The rounding of the stems and branches of crystallites, which was a particular feature in metals and alloys, was probably to be accounted for by surface tension effects, although the present ignorance of the surface tension constant of metals made it impossible to give a quantitative explanation of the phenomena. The author draws attention to the peculiarity of the crystallisation of certain eutectic mixtures, the external form of which recalled that of a single pure substance. In such "colonies" or pseudo-crystals the form was due to the dominant orientating force of one of the constituents, the other behaving as a plastic filling material.

N. J. Wark,¹ in experimenting on the solubility of carbides in iron, observed that martensite separated in such a form as to point to the existence of large crystalline aggregates, a structure indicative of overheated or burnt material, and it appeared to be of interest to study the conditions under which the structure was obtained. Specimens containing 0.11 to 1.672 per cent. of carbon and about 0.1 per cent. of manganese were prepared and two series of experiments were carried out. The first consisted in examining microscopically sections which had been heated to different degrees of high temperature for thirty minutes and quenched. In the second series sections were etched at high temperatures by means of dry hydrochloric acid gas. The development of a polygonal structure depends largely upon the length of the heating period, and a temperature limit could not be fixed for its formation. The results, however, appear to show that the polyhedral structure is that of the homogeneous austenite solution. The tendency towards super-cooling in high-carbon steels is much greater than in low-carbon steels, and it is therefore necessary to heat the low-carbon steels to a higher point above the equilibrium temperature in order that the polygonal structure may persist after quenching.

E. F. Lange² describes and illustrates some remarkable pine-tree shaped steel crystals, of a size up to 15 inches in length, which were found in the pipe formed in the riser of a large steel casting. Some notes on the crystalline structure of steel are given.

¹ *Metallurgie*, vol. viii. pp. 731-737.

² *Manchester Literary and Philosophical Society*, vol. lv. No. 24, pp 1-15.

Metallography and Microstructure.—J. E. Stead¹ deals with micro-metallography and its practical application.

W. Rosenhain² discusses the microstructure of steel, with special reference to the changes which occur during its hardening and tempering and the structural alterations which supervene on heating the mildest steel and even pure iron. With reference to the question as to whether overheated steel can be restored by heat treatment, it is pointed out that on passing through the critical range on heating a fresh set of crystals is formed which are at first small, but rapidly increase in size. If a piece of overheated steel is reheated to a temperature just above the critical range and then rapidly cooled, a fine crystalline structure might be hoped for, but some connection exists between the number of crystals existing above and below the critical ranges, so that in certain cases a piece of steel reheated in this way returns exactly to the condition from which it started. Simple heat refining may sometimes be successful, but its effects are uncertain. The influence of welding and welding temperatures on the structure are also considered, and the nature of slipbands is explained with diagrams, together with the effects of strain on microstructure, illustrated by sectional photomicrographs.

H. M. Howe³ discusses the life-history of cells and grains in steel, and describes their mechanism. His conclusions are thus summed up: (1) The term "grain size" should be restricted to the size of the individual islets of ferrite or cementite, and the size of the cells bounded by walls of ferrite or cementite should be called "cell size." (2) Both grain size and cell size increase not only with the temperature reached when above the critical range, but with the length of exposure to that and neighbouring temperatures. (3) The visible cell structure, the coarse cleavage massing, the finer cleavage massing, and the break-up of the cell structure through spheroidising, coalescence, and the formation of irregular ferrite grains, are successive but overlapping stages in the evolution of the structure of steel. (4) The effect of high and long heating in coarsening the cell size represents the coarsening of the austenite grains during that high heating, each such grain being later represented by a single cell. (5) The effect of high and long heating in coarsening the ferrite grain, in increasing the area free from visible ferrite in the air-cooled steel, in lowering the critical range, in increasing the stability of the red-hardness of high-speed steel and the stability of the cellular structure, in increasing the massing of ferrite and cementite into the octahedral cleavages of the austenite, and in retarding the coagulation of sorbite into pearlite, represent the greater perfection, efficiency, and stability of the crystalline organisation reached in the austenite stage; this stability giving the austenite structure great pseudomorphous restraining power *de facto*, even after its existence *de jure* has ceased with the passage to below the transformation range. (6) The influence

¹ *Journal of the West of Scotland Iron and Steel Institute*, vol. xix. pp. 169-204.

² *Automobile Engineer*, vol. ii. pp. 42-43, 71-72, 164-165.

³ *Proceedings of the American Society for Testing Materials*, vol. xi. pp. 362-386; *International Journal of Metallography*, vol. ii. pp. 11-25.

of manganese in emphasising the cell structure is simply one aspect of its general retarding effect.

G. A. Roush¹ discusses an investigation of carbon by microscopic methods. Commercial products of carbon consist of small amorphous particles of carbon which differ in appearance from one another, the differences being clearly recognisable under the microscope, which enables the character and composition of various carbon products to be identified. The specimens for examination are prepared in the same way as specimens of metals and alloys. Petroleum coke appears as a porous mass, the microstructure of which shows large pores interspersed through the finer structure of a cellular character. The typical feature of petroleum coke is the corrugated appearance of the surface. Artificial graphite has no particular characteristic structure, whereas natural graphite is of a flaky appearance, which enables it to be distinguished with certainty.

In dealing with the application of the microscope to the examination of metals, A. Campion² demonstrates by means of a large number of photomicrographic lantern slides the constitution of various metals, and shows the numerous structures and inclusions which give rise to defects in metals, dividing these into three groups: chemical, mechanical, and thermal. Of the first class examples were shown of fractures caused by the presence of sulphide of iron, sulphide of manganese, and silicate of iron; while as examples of mechanical defects there were shown fractures caused by the inclusion of scale, by the segregation of carbide of iron, and by quenching. The effects of heating and cooling on various metals are illustrated and explained, together with diagrams of the solidification of metals.

A. Sauveur³ deals with the calculation of the structural composition of steel and its physical properties.

O. Mügge⁴ describes some etching experiments that were made on crystals and plates of magnetite and of some other minerals of the spinel group. A description and microphotographs are given of the resulting etched surfaces.

Formation of Troostite.—D. K. Bullens⁵ summarises the views of a number of observers regarding the formation of troostite, and points out that the general tendency of thought at the present time seems to be towards Benedicks' proposition of an ultra-microscopic pearlite, regarding troostite as an aggregate. There are still, however, a large number of investigators who maintain that troostite is a solution of carbon or carbide in allotropic iron. Experiments were carried out on pure iron-carbon alloys, both of eutectoid and hyper-eutectoid character:—

¹ *Journal of Industrial and Engineering Chemistry*, vol. iii. p. 368.

² Paper read before the Glasgow Microscopical Society; *Mechanical Engineer*, vol. xxix. p. 314.

³ *Journal of the Franklin Institute*, vol. clxxiii. pp. 499-508.

⁴ *Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie, Beilage*, vol. xxxii. pp. 491-534.

⁵ *Metallurgical and Chemical Engineering*, vol. x. pp. 205-207.

	Eutectoid.	Hyper-Eutectoid.
	Per Cent.	Per Cent.
Carbon	0.82	1.48
Manganese . . .	0.14	0.16
Sulphur	0.111	0.006
Phosphorus . . .	0.009	0.009
Silicon	0.14	0.14

The conclusion is arrived at, as the result of metallographic investigation, that the masses generally known as troostite may be termed osmondite, and that change after segregation is so rapid that the resolution of the segregated troostite takes place almost immediately, giving osmondite and cementite.

Structure of Micro-constituents of Steel.—M. Oknof¹ has continued his investigations of the internal structure of the micro-constituents of steel. The method previously employed by him² was again adopted for the study of martensite and pearlite—that is, a number of layers were removed by successive polishings from the surface of the steel specimen under investigation. In the case of martensite the layers removed were 0.015 millimetre thick, and in that of pearlite they had a thickness of 0.01 millimetre. An examination of eighteen photomicrographs shows that martensite occurs in the form of flat lamellar crystals with a length equal to about seven times the width. Pearlite consists of narrow curved layers of cementite embedded in a ferrite mass. Some of the cementite layers intersect and verge into each other, but most of them remain parallel in the succeeding layers. The lamellæ of martensite and pearlite differ in size.

Osmondite in Hypo-eutectic Steels.—J. Calian³ has investigated the formation of osmondite in hypo-eutectic steels. The presence of osmondite in steel was proved by Heyn and Bauer by etching steel with alcoholic hydrochloric acid. The experiments were carried out on a steel containing 0.95 per cent. of carbon, then with a eutectic steel containing nothing but pearlite. In the experiments described, however, three hypo-eutectic open-hearth steels and one hyper-eutectic steel were examined. The first three steels contained ferrite and pearlite, and the fourth cementite and pearlite. The etching was carried out for a period of time which was inversely proportional to the temperature of annealing. Photomicrographs of the results are given together with curves showing the solubility of the various constituents. The experiments led to the following conclusions:—

(1) In hypo-eutectic steels martensite undergoes, during its transformation into pearlite, the same states as in a eutectic steel, that

¹ *Metallurgie*, vol. viii. pp. 539-541.

² *Ibid.*, vol. viii. pp. 138-139.

³ *Revue de Metallurgie, Mémoires*, vol. ix. pp. 187-194.

is to say, martensite, troostite, osmondite, sorbite, pearlite. (2) Osmondite, which is an intermediary state, does not form at any particular temperature, but occurs between 300° and 500° . (3) The structure of osmondite has no connection with the amount of free carbon or carbide, but depends on the arrangement of the molecules and the composition of the original material. It may be explained by the fact that as the percentage of carbon diminishes that of carbide increases.

A Fourth Recalescence Point.—J. O. Arnold,¹ in referring to the statement of W. Rosenhain² that although the discovery of the fourth recalescence in steel was announced last year, yet a clear account of the double nature of Ar_2 is given by Osmond in his paper read in 1890,³ points out that in Osmond's actual curves will be found one of electrolytic iron which exhibits something like the two peaks of Ar_2 , but since in this curve there are three extra critical points, obviously due to errors of observation, it is most probable that the second peak of Ar_2 is also due to errors of the instrument. In four other curves of steel exhibited by Osmond in which the point Ar_2 is separate, it is in every case figured as a single point. It is also pointed out that in the work of Carpenter⁴ and Keeling curves of five mild steels are given, in all of which the point Ar_2 is represented as a single point. The author states that the fourth recalescence of steel has no connection whatever with the Ar_2 point as suggested by Rosenhain.

W. Rosenhain⁵ replies to J. O. Arnold's criticism of his lecture.

Critical Points in Chromium Steel.—A. Portevin⁶ points out that investigations made on chromium steels have shown that those containing about 0.1 per cent. of carbon and 7 to 22 per cent. of chromium are martensitic, which would imply that a transformation occurs at a low temperature on cooling. The action of a special element like chromium may have a dual effect on the transformation points. It may displace the equilibrium temperatures, and it may modify the rate of equilibrium and, as a result, the hysteresis. In order to clear up these points experiments were made on two samples of chromium steel, containing 0.12 per cent. of carbon and 13.04 and 17.38 per cent. of chromium respectively. The samples were heated at 1300° and then cooled, so that the temperature interval $1300 - 100$ was spread over 75 hours. The microstructure of the steels and their behaviour under hardness tests show that these steels after a treatment of this description resemble ordinary carbon steels that have been annealed. A further annealing under ordinary conditions such

¹ *Engineer*, vol. cxiii. p. 129.

² *Proceedings of the Institution of Mechanical Engineers*, April 1911, p. 243.

³ *Journal of the Iron and Steel Institute*, 1890, No. 1. p. 46.

⁴ *Ibid.*, 1904, No. 1. p. 224.

⁵ *Engineering*, vol. xciii. p. 181.

⁶ *Revue de Metallurgie, Mémoires*. vol. viii. pp. 802-803.

as is frequently carried out in practice confers on such steels the effect of quenching. It brings out the martensitic structure and considerably increases the hardness.

Nature of Solid Solutions.—C. A. Edwards,¹ in continuation of his previous paper, now discusses the nature of solutions in general—gaseous, liquid, and solid—and points out that the phase rule in its present form is based on the assumption that solutions are homogeneous, and hence cannot be used to determine the internal nature of a solution.

The Artificial Crystallisation of Carbon.—S. M. Howell² criticises published accounts of the crystallisation of carbon by artificial means, and after referring to the experiments of Moissan, Friedel, Hanney, and Sir William Crookes, suggests methods for the crystallisation of carbon by the decomposition of hydrocarbon liquids or of carbon bisulphide under pressure. The use of acetylene is also suggested.

The Iron-carbon System.—A. Smits³ considers that the theory that cementite occurs in the iron-carbon system in a metastable condition does not solve the problem of the formation of cementite at temperatures considerably below the eutectic temperature. By varying the rate of cooling, graphite or cementite can be separated from the liquid, from which the author assumes that both cementite and graphite are present in equilibrium. On slow cooling graphite separates out, and the liquid never becomes supersaturated as regards cementite. On the other hand, the separation of graphite is prevented by rapid cooling, and the liquid becomes relatively supersaturated with cementite, which then separates.

S. W. J. Smith,⁴ W. White, and S. G. Barker discuss the magnetic transition temperature of cementite. The temperature at which cementite loses its ferro-magnetism is determined with sufficient accuracy for purposes of thermo-magnetic analysis, and examples are given to show how the thermo-magnetic properties of cementite may be turned to account for the purpose of ascertaining whether that constituent is present in any iron-carbon alloy.

In a theoretical paper R. Schenck⁵ discusses from the point of view of the phase rule and of thermodynamics numerous chemical equilibria involved in the manufacture of iron and steel.

Crystallisation and Transformations in Iron containing over 4 per Cent. of Carbon.—N. M. von Wittorf⁶ has carried out an exhaustive investigation of the thermal behaviour and micrography of iron-carbon alloys, with over 4 per cent. of carbon, the main results

¹ *Journal of the Institute of Metals*, vol. vi. pp. 259–278.

² *Metallurgical and Chemical Engineering*, vol. x. pp. 197–198.

³ *Zeitschrift für Elektrochemie*, vol. xviii. pp. 51–54.

⁴ Paper read before the Royal Society, December 7, 1911.

⁵ *Stahl und Eisen*, vol. xxxi. pp. 1745–1752.

⁶ *Journal of the Russian Physical and Chemical Society*, vol. xliii. pp. 1613–1690.

of which are as follows: Melts containing from 6.2 to 10 per cent. of carbon begin to crystallise at 2000° – 2380° C. under separation of a carbide, thought to correspond to FeC_3 , which is of a pale sulphur-yellow colour, and gives a silvery reflection. This constituent is very slowly attacked by nitric acid, and if treated with very dilute copper sulphate solution it becomes coated with copper. The nitric acid attack yields a dark residue. The same carbide crystallises when the melt attains a temperature of 2600° . In cooling from 2000° to 1700° , the first constituent to separate out is pure cementite. In the temperature range 1650° to 1330° the melt burns, the burning being particularly noticeable in samples containing 7 per cent. of carbon. If the melt is stirred, thin tubular crystals appear on the surface, which, it is conjectured, may be the carbide FeC , and at a temperature of about 1600° these crystals take the form of long arrows with angular projections. Below 1700° the melts always contained these arrows enveloped in a metallic compound rich in carbon, forming dendritic masses on a eutectic-like foundation. This compound is not appreciably etched by 4 per cent. alcoholic picric acid solution or by dilute sulphuric acid if hardened at a temperature not lower than 1160° , but, unlike cementite, it is energetically attacked by 1:4 nitric acid. The quantity of this compound separating out increases from 0 to 100 per cent. as the carbon concentration in the melt is increased from 4.1 to 5 per cent. In melts containing 6 or 7 per cent. of carbon the basic mass of metal consists of this compound and of the arrow-like residuum, its composition being represented by the formula Fe_4C . Below 1130° the carbide Fe_4C decomposes into γ -solution and graphite. The carbides crystallising above 2000° and at 1600° – 1400° decompose with the separation of graphite.

Solubility of Cementite in γ -Iron.—N. J. Wark¹ has made experiments for the purpose of determining the solubility curve of γ -iron for cementite. Ten samples of steel were prepared by melting white Swedish pig iron and horse-hoe nail iron in magnesia crucibles, the composition of the specimens being, carbon 1.2 to 1.96 per cent., manganese 0.07 to 0.09 per cent., silicon 0.03 to 0.05 per cent. They were heated in a salt bath and quenched in water. A microscopic examination of each specimen was made to ascertain the temperature at which cementite began to separate out, and the results, which are plotted in the curve, confirm Gutowsky's observation that 1.7 per cent. is the saturation point of carbon at 1130° C.

Heat of Formation of Iron Carbide.—O. Ruff² and E. Gersten have carried out further experiments on the heat of formation of iron carbide. The method is given for the preparation of the carbide, which in appearance was dark grey, and consisted mainly of fragments of globular aggregates of needle-shaped crystals; it was very

¹ *Metallurgie*, vol. viii, pp. 704–713.

² *Berichte*, vol. xlv, pp. 63–72.

brittle and could be powdered in the hand. The hardness lies between 3.2 and 3.3, so that it cannot itself be the cause of the hardness of rapidly cooled steel, which is probably due to the solid solution of the carbide in γ -iron: $D^{21} = 7.396$, the molecular volume being 24.34. The molecular heat of combustion determined in a bomb calorimeter was found to be 375.1 calories, the products of combustion being carbon dioxide and ferroso-ferric oxide. The molecular heat of formation of ferroso-ferric oxide was found to be 265.2 calories. Pure Swedish iron (99.745 per cent.) and iron prepared from pure ferric chloride were used in these experiments, allowance being made for the heat of combustion of the traces of impurities present in the Swedish iron. From the molecular heats of formation of ferroso-ferric oxide and of carbon dioxide (from graphite = 94.8 calories), and from the molecular heat of combustion of iron carbide to ferroso-ferric oxide and carbon dioxide, the heat of formation of iron carbide (Fe_3C) is found to be -15.1 calories.

Transformation of Carbon into Graphite.—W. C. Arsem¹ gives the results of his investigation undertaken with a view to ascertaining whether a pure form of carbon can be transformed into graphite by simply heating to a high temperature, and, if not, whether it is possible to cause this transformation by heating the carbon, well mixed with a quantity of mineral matter insufficient to form carbides, with all the carbon present.

Iron, Nickel, and Copper Alloy.—A new white, non-corrosive, and malleable alloy of iron, nickel, and copper has been patented by G. H. Clamer.² Pure copper and iron will alloy in all proportions and form a homogeneous mixture; but when carbon is present, as it is in steel or cast iron, the two metals do not alloy well, hard nodules separating according to the amount of carbon. In the alloy described it is stated that the tensile strength is increased if carbon is present in an amount not exceeding 0.2 per cent. The strength of the alloy is high, a mixture of iron 65 per cent., nickel 25 per cent., copper 10 per cent., and carbon 0.2 per cent., having the following physical properties: tensile strength, 96,100 lbs. per square inch; elastic limit, 51,750 lbs. per square inch.; elongation in 2 inches, 42 per cent.; reduction in area, 53.7 per cent.

Alloys in Construction of Automobiles.—H. Souther³ gives the composition and specific gravities of the most useful aluminium alloys in automobile construction.

Ferro-magnetic Compounds of Manganese.—S. Hilpert⁴ and T. Dieckmann state that manganese forms ferro-magnetic compounds

¹ *Chemical Engineer*, vol. xiv. No. 4; *Chemical News*, vol. cv. pp. 38-40, 50-53.

² *Mechanical Engineer*, vol. xxix. p. 411.

³ *Cycle and Automobile Trade Journal*; *Mechanical Engineer*, vol. xxviii. pp. 186-187.

⁴ *Berichte*, vol. xlv. pp. 2831-2835.

with phosphorus, arsenic, antimony, and bismuth. On heating, the magnetisability disappears within a short range of temperature, re-appearing on cooling. The critical range of temperature varies with the compound, and rises on passing from phosphorus to bismuth. The phosphide was prepared by heating pure manganese prepared from the electrolytic amalgam with red phosphorus in a sealed tube to 600°C . After extracting the product with dilute hydrochloric acid an insoluble residue was left. This may be obtained containing 36.1 per cent. of phosphorus (MnP) or higher percentages up to nearly that corresponding to MnP_3 . The critical temperature (18° to 26°C .) does not vary with the phosphorus content, but the magnetisability is smaller in the specimens containing a higher percentage of phosphorus. The arsenide has a critical temperature of 40° to 45°C .; while the antimonide and bismuthide have critical temperatures of 320° to 330°C . and 360° to 380°C . respectively.

Arsenides of Iron and Manganese.—S. Hilpert¹ and T. Dieckmann describe a method of producing metallic arsenides by heating powdered metallic manganese or iron with excess of arsenic in a sealed Jena glass tube to 600° to 700°C . for about six hours. The arsenides so formed can be easily separated mechanically in a state of purity.

Rate of Diffusion of Hydrogen in Steel.—G. Charpy² and S. Bonnerot have measured the rate of diffusion of hydrogen into thin-walled steel cylinders at different temperatures, and find that whilst practically no diffusion occurs under atmospheric pressure below 325° , osmosis is perceptible at 350° , and is about forty times as rapid at 850° . Nascent hydrogen acquires special chemical activity in diffusing through iron and steel at ordinary temperatures. On placing a steel cylinder in acid, or making it the cathode in a solution of sodium hydroxide, hydrogen diffused through the interior of the cylinder, but if the surface from which the hydrogen was liberated was placed a few millimetres from the cylinder the diffusion did not take place. The thickness of the walls, the nature of the metal, and also the interior pressure cause a variation in the rate of diffusion. It is shown by preliminary experiments that diffusion is not inhibited by a pressure of 14 atmospheres.

Solubility of Hydrogen in Copper, Iron, and Nickel.—A. Sieverts³ gives the results of his investigations on the solubility of hydrogen in copper, iron, and nickel, which he has determined for pressures up to $1\frac{1}{2}$ atmospheres, and at intervals of temperature from 400° to 1600° . At constant temperature the solubility in solid and

¹ *Berichte*, vol. xliv. pp. 2378–2385.

² *Comptes Rendus*, vol. cliv. pp. 592–594.

³ *Zeitschrift für physikalische Chemie*, vol. lxxvii. pp. 591–613.

fused metals is proportional to the square root of the pressure, but below 100 millimetres pressure the amount of hydrogen taken up diminishes rather more rapidly with the pressure than the above rule would indicate. Solubility increases with the temperature at constant pressure, and also increases suddenly when the metal melts. All three metals give up hydrogen accompanied by "spitting" when they solidify in an atmosphere of gas. At the respective melting points copper gives up 2 volumes, iron 7 volumes, and nickel 12 volumes of the gas.

Composition of Raw Metal for Tinplate.—J. Lasskowski¹ discusses the chemical composition of the raw materials used in the manufacture of tinplate. As a rule the final product should contain a fairly high percentage of phosphorus. It is pointed out that if the charges are poor in phosphorus good results may yet be obtained by the use of ferro-silicon.

Heat Formation of Silicates.—D. Tschernobaeff² and L. Wologdine have studied the heat of formation of various silicates and aluminosilicates, by burning mixtures of the substance under investigation with wood charcoal in a Mahler's calorimetric bomb, and finding the difference between the quantity of heat disengaged by burning the carbon and the observed quantity. The results were as follows:—

	Per Cent.
$\text{SiO}_2 + \text{CaO}$	= +17.4
$\text{SiO}_2 + 2\text{CaO}$	= +28.7
$2\text{SiO}_2, \text{Al}_2\text{O}_3 + 3\text{CaO}$	= +50.2
$2\text{SiO}_2, \text{Al}_2\text{O}_3 + 3\text{CaO}$	= +38.2
$\text{SiO}_2 + \text{Al}_2\text{O}_3$	= -12.0

Thus the heat of formation of anhydrous kaolin, $2\text{SiO}_2, \text{Al}_2\text{O}_3$, is negative.

Properties of Tungsten and Molybdenum.—W. D. Coolidge³ describes several possible applications of wrought tungsten and molybdenum. Wires of those metals are cheaper than, and far superior to, platinum as a winding for electric furnaces, and when used upon an alundum body, higher temperatures can be obtained than with platinum. Tungsten and molybdenum appear eminently suitable for electrical contact devices, owing to their high melting point, heat conductivity, and hardness.

Properties of Vanadium.—According to O. Ruff⁴ and W. Martin vanadium trioxide, melting at 2000° , gives better results in the preparation of pure vanadium than the pentoxide, on account of the ready fusibility of the latter, which causes it to pass into the slag.

¹ *Gorni Journal*, 1911, pp. 210-226; *Stahl und Eisen*, vol. xxxii. p. 281.

² *Comptes Rendus*, vol. cliv. pp. 206-208.

³ *Journal of Industrial and Engineering Chemistry*, vol. iv. pp. 2-4.

⁴ *Zeitschrift für angewandte Chemie*, vol. xxv. pp. 49-56.

Vanadium trioxide, prepared by reducing the pentoxide in hydrogen below 550° , is mixed with aluminium and 2 per cent. of powdered carbon, and pressed into a crucible lined with magnesia. After adding a layer of ignition mixture, the crucible is covered and heated to redness. The product contains 95 per cent. of vanadium.

A less pure product is obtained by reduction with carbon in an arc. By moulding mixtures of the trioxide and carbon with starch into rods, sintering in an electric furnace at 1750° , and finally fusing in an arc, products containing 95 to 97 per cent. of vanadium are obtained. The impurity consists of carbon or oxygen, according to the proportions employed.

The melting points of different specimens of vanadium have been determined by heating in an electric vacuum furnace. Either oxygen or carbon raises the melting point of vanadium, and by extrapolating the two curves obtained from mixtures containing varying quantities of carbon and of oxygen, pure vanadium is found to melt at 1715° . The raising of the melting point is due to the formation of solid solutions with the oxide VO and the carbide. The density is also found by extrapolation, being lowered by impurities. The pure metal has $D^{18.75}_{688}$. The heat of combustion of 1 gramme of the pentoxide is 2456 calories.

Temperature of Formation of Titanium Dioxide.—W. G. Mixer¹ has redetermined the heat of formation of titanium dioxide by combustion of the finely divided metal in oxygen. The most trustworthy observations give $Ti + O_2 = TiO_2$ (crystalline) + 218.4 calories. This is about 1.1 per cent. higher than the value obtained previously by the sodium peroxide method. Both values are in complete disagreement with that given by L. Weiss² and H. Kaiser, which is only 97.77 calories.

Duraluminium.—The properties of the alloy,³ known as duraluminium, are described. Its composition is:—

	Per Cent.
Aluminium	93-96
Copper	3.5-5.5
Manganese	0.5-0.8
Magnesia	0.5

This alloy is three times as hard as pure aluminium. Its modulus of elasticity is 700 kilogrammes per square centimetre. It melts at 650° , and it is more refractory than pure aluminium to the action of chemical reagents.

Melting Points of Metals.—The results of an investigation⁴ carried out at the University of Wisconsin show that the melting point of tungsten is $3002^{\circ}C$., and of tantalum $2798^{\circ}C$., these values being somewhat different from the generally accepted ones. The

¹ *American Journal of Science*, vol. xxxiii. pp. 45-48.

² *Zeitschrift für anorganische Chemie*, vol. lxx. pp. 345-402.

³ *Lumière Electrique*, vol. xxvi. p. 53.

⁴ *Electrical World; Engineer*, vol. cxiii. p. 325.

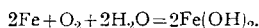
measurements were taken with great care, using the optical pyrometer, and a direct-vision prism giving monochromatic light.

K. Burgess¹ gives a table summarising the most recent determinations of the melting points of elements. This gives the following values:—

Manganese	1225±15
Silicon	1420±15
Nickel	1450±10
Cobalt	1490
Chromium	1505±15
Iron	1520±15
Vanadium	1730±30
Titanium	{ 2200 to 2400?
	{ 1800 to 1850?
Molybdenum	2500?
Tungsten	3000±100
Carbon	unknown.

Ferro-silicon Explosions.—A. von Gumberz² gives a short account of two explosions, occurring in April and September 1911, with ferro-silicon at the Bismarck Ironworks. Several of the contributors to the discussion attributed the explosions to the presence of moisture in the ladle.

Corrosion of Iron.—G. J. Burrows³ and C. E. Fawsitt deal with the corrosion of steel in water. The authors believe that the formation of a ferrous compound in the first stage of rusting follows the equation



It does not appear likely that the oxygen and water together act simultaneously on the iron. It is more probable that the iron first dissolves to a very limited extent in the water. It is known to be capable of dissolving to a small extent in water as ferrous iron, displacing at the same time an equivalent quantity of hydrogen. The hydrogen, in the absence of free oxygen, polarises the iron surface, and the function of the oxygen is to remove the layer of polarising hydrogen. According to this view, iron should dissolve faster if it be in contact with a more electro-negative metal like platinum, for then the hydrogen would tend to collect more on the platinum plate than on the iron one. The acceleration of corrosion caused by contact with platinum is shown in the following table:—

	Weight at Start.	Loss of Weight after 17 Days.	Loss of Weight after 35 Days.
	Grammes.	Grammes.	Grammes.
Steel	64·563	0·141	0·258
Steel with platinum . . .	64·619	0·185	0·326
Steel	65·371	...	0·273
Steel with platinum . . .	63·382	...	0·303

¹ *Journal of the Washington Academy of Sciences*, vol. i. p. 16.

² *Stahl und Eisen*, vol. xxxii. pp. 267–271.

³ *Journal of the Royal Society of New South Wales*, vol. xlv. pp. 67–75.

The steel strips had the following composition: Carbon 0·35, manganese 0·61, phosphorus 0·06, silicon 0·01, sulphur 0·01 per cent. They were fully immersed in unstirred distilled water. In all the experiments, those in any series were placed together in one part of a room. The temperature of the experiments was the temperature of the room, and therefore was not constant, but varied in the same manner for each individual test in any series. The corrosion was determined by removing the steel after an appropriate time, scrubbing the surface well with a brush, drying and weighing. Corrosion is then expressed as loss of weight. The authors also discuss the influence of composition and of the magnetic condition of steel on its corrosion. Experiments were also conducted primarily with the object of testing the action of some artesian bore waters on steel. It has been supposed for some time that the bore waters in the Coonamble district have an extra corrosive effect on steel or iron castings. These experiments show—(1) that the bore waters tested are not noticeably more corrosive than distilled water, (2) that moderate stirring of the solution has an accelerative effect on the rusting process, (3) that the initial rate of corrosion does not stand in any simple relation to the rate which sets in after some time has elapsed.

T. Turner¹ in his presidential address to the Metallurgical Society of the Birmingham University, states that experiments on corrosion, conducted at the University, show that when cast iron is attacked by weak acids the iron is first dissolved; the carbides and phosphides offering better resistance. With alkaline corrosion, on the other hand, the impurities were first dissolved, and the pure iron remained till last.

A curious case of the failure of a screwed bolt-stay in the boiler of the steam trawler *Clyne Castle* is reported.² The stay, which was $1\frac{3}{4}$ inches in diameter, together with the plate through which it passed, which was $1\frac{1}{2}$ inches thick, was eaten almost away as if by the action of some powerful acid, with the result that the outside head was left so slightly attached that it was blown off at the ordinary working pressure of 180 lbs. No sign of corrosion was visible elsewhere in the boiler, and there was nothing in its construction or working which could suggest any explanation of the severity and local character of the wasting. At the inquiry that was held all possible explanations were examined, but none afforded a clue to the severe isolated patch of corrosion covered by a radius slightly less than 3 inches from the centre of the stay.

H. Pilkington³ compares wrought iron and basic mild steel as regards corrosion, mechanical structure, strength, and the mechanical tests involved.

Corrosion of Iron Pipes.—The corrosion of iron and other metallic pipes is considered,⁴ and numerous clear photographs are

¹ *Mechanical Engineer*, vol. xxviii. p. 579.

² *Board of Trade Report*, No. 2066; *Mechanical Engineer*, vol. xxviii. p. 761.

³ *Journal of the West of Scotland Iron and Steel Institute*, vol. xix. pp. 245-264.

⁴ *Stahl und Eisen*, vol. xxxi. pp. 1485-1493.

shown illustrating special cases of corrosion. It is pointed out that weakness and corrosion may result from internal and external causes. To the former belong such factors as inequality and chemical activity of the material composing the pipes, existence of stresses, and porosity. Amongst the external causes are grouped the mechanical and chemical action of the surroundings, such as, for example, the pressure, temperature, and chemical activity of the water, soil, or air. Electric and galvanic forces are particularly severe, the latter leading to the conversion of cast iron into a mass of graphite, by removal of the iron, which mass retains the original shape, but none of the strength, of the casting. The consequences are thus liable to prove very serious, inasmuch as the corrosion is not capable of immediate detection.

A case of the corrosion¹ of a wrought-iron steam pipe and cast-iron valves of a boiler plant have been traced to the use of soda in the feed-water as a scale softener. It was found on examination that the dry steam pipes had been strongly corroded, while the wet steam pipes were in good condition. It was evident that soda particles had been carried by the steam, and had dried on the dry pipes, thus forming a white incrustation; while the wet steam had prevented the formation of a solid deposit. Soda dissociates into caustic soda and carbonic acid at high pressure and temperature, and it is known that in the presence of water and oxygen carbonic acid attacks iron. It is further known from the recent researches of Heyn and Bauer that diluted caustic soda corrodes iron.

F. N. Speller² discusses the influence of the method of manufacture on corrosion of soft steel tubes, and gives a table of comparisons of the corrosion of boiler tube materials in aerated water and sulphuric acid.

Electrolytic Corrosion.—J. L. R. Hayden³ has studied the problem of corrosion produced by stray currents in the ground, and some preliminary results of an investigation of the corrosion of iron under the influence of an electric current are given. A 1 per cent. solution of ammonium nitrate was first used as the electrolyte, as nitrates and ammonia salts are the most probable conducting compounds in soils, especially in cities. As the electrolytic corrosion of the iron was found to be much lower than the theoretical value, tests were made to see whether this was due to a partial corrosion or to periods in which no corrosion took place. The results indicate that there is no partial corrosion, but that the iron is either passive, that is, practically no corrosion takes place, or active, that is, full theoretical corrosion occurs. Fractional values of the theoretical corrosion are observed only where the cell has been operated continuously for a considerable time, and apparently had started active and become passive. In the experiments described the active state

¹ "Vulcan," *Engineer*, vol. cxiii, p. 301.

² *Journal of the Society of Chemical Industry*, vol. xxx, pp. 263-265.

³ *Journal of the Franklin Institute*, vol. clxxii, pp. 295-303.

occurred eight times, the passive state ten times, and three times the corrosion was intermediate between the two states. Other electrolytes were investigated, those of special interest being potassium nitrate, ammonium nitrate, and ammonium carbonate. All three give a corrosion which is appreciable, but only 25 to 38 per cent. of the theoretical, and all three show a sudden voltage rise during the run. It is thus safe to assume that with these electrolytes the cells start active, but become passive during the earlier part of the run.

G. R. White¹ has studied the electrolytic corrosion of zinc, copper, nickel, tin, iron, and cadmium, when these metals are made anodes in solutions of sodium chloride, sulphate, nitrate, acetate, and tartrate, containing 75 grammes of salt per litre. The metals corroded to different extents in different solutions, although the same metal often corroded to the same extent in two and sometimes in three electrolytes. The corrosion in some cases corresponded very closely with the theoretical amount calculated from the current, but it was often very much less, and occasionally very much greater. When the corrosion was very much less than the theoretical, it was found that further action was prevented by the formation of a hydroxide or oxide film on the anode. In some cases the formation of this film could be detected by a marked increase in the resistance of the circuit. When corrosion was greater than the theoretical quantity, the excess was not found to be due to loss of metal by mechanical disintegration. In such cases it is probable that the metal went into solution in a subvalent form.

Corrosion of Iron in Contact with Slag.—E. Heyn² and O. Bauer have carried out a series of experiments to determine the susceptibility of low-carbon steel to rust attack when in contact with blast-furnace slag. This latter material is now often used for the packing of steel sleepers on railways in certain industrial districts in Germany, and it is therefore of importance to discover whether the sulphide sulphur always present in slag does not become oxidised by exposure to the weather to sulphuric acid and seriously attack the metal in contact with it. A number of experiments were made with strips of bright steel placed in jars containing a definite weight of slag moistened with distilled water. Four sorts of slag were used, the sulphate of lime contained varying from 3.96 to 6.68 per cent. The steel strips contained—carbon 0.04, silicon 0.01, manganese 0.59, phosphorus 0.034, sulphur 0.025, copper 0.16 per cent. For comparison, some of the strips were also placed in jars containing ordinary gravel, and were moistened in the same way with distilled water. The weight of each strip averaged about 9.5 grammes. At the end of twenty-two days the strips in contact with the slag, in one of the series of experiments, were all strongly

¹ *Journal of Physical Chemistry*, vol. xv, pp. 723-792.

² *Mitteilungen aus dem kgl. Materialprüfungsamt*, vol. xxix, pp. 454-461.

corroded, the loss in weight amounting to 0.1289 gramme in the case of the least attacked specimen, to 0.1458 gramme in the most strongly attacked. The specimen in contact with gravel in the same time lost 0.0297 gramme.

Corrosion of Iron in Concrete.—E. Donath¹ states that experiments do not confirm Rohland's view that the active agent in the removal of rust from iron in reinforced concrete is calcium hydrogen carbonate. Only that part of the ferric iron which is in combination with ferrous oxide is converted into calcium ferrite.

P. Rohland² replies to Donath's criticisms.

Passivity of Iron.—In continuation of their previous work, W. R. Dunstan³ and J. R. Hill have investigated the cause of the inhibiting effect of certain substances, such as alkalis and potassium dichromate, on the rusting of iron and other metals. It has been found that this effect is in all cases the result of the establishment of a passive condition of the iron. The effect persists long after the metal has been removed from the inhibiting solution and carefully washed with water. The passivity is more or less rapidly destroyed by contact of the iron with certain salts or dilute acids, including carbonic acid. It is pointed out that the facts now recorded invalidate many of the results recently quoted in support of the carbonic acid theory of rusting, and further evidence is produced in favour of the conclusion maintained in previous papers, that the presence of carbonic acid is not essential to the rusting process. Results of experiments are recorded, showing that the electrolytic theory of rusting cannot be maintained, and it is also shown that other metals besides iron exhibit the phenomena of rusting, and are also capable of assuming the passive state.

W. R. Dunstan⁴ and J. R. Hill find that the passive state of iron is induced by solutions, in many cases by dilute solutions of a number of salts, such as potassium dichromate, chromate, iodate, chlorate, ferrocyanide, and also by alkalis and alkaline salts, and that, besides iron and metals of the iron group, other metals, including magnesium, lead, zinc, and copper, are also capable of assuming the passive state under the same conditions. In addition to being destroyed by contact with certain salts and dilute acids, passivity can be removed by scratching or brushing the surface of the passive metal, as well as by other mechanical means. The evidence obtained points strongly to the conclusion that passivity is the result of the formation of a film on the surface of the metal. The results of experiments show that this film probably does not consist of "physically" altered metal or of a gas film. The passivity of iron is destroyed by heating in a vacuum

¹ *Zeitschrift für angewandte Chemie*, vol. xxiv. pp. 2355-2356.

² *Ibid.*, p. 2356.

³ *Transactions of the Chemical Society*, vol. xcix. pp. 1835-1853.

⁴ *Ibid.*, pp. 1853-1866.

to 400°, and disappears when passive iron is heated in hydrogen to 240–250°, at which temperature it is known that magnetic oxide of iron is reducible by hydrogen. The observed facts point to the conclusion that “passivity” is probably the result of the formation of a solid film of oxide on the surface of the metal. It has not, however, been hitherto recognised that certain metals, and especially iron, are capable of oxidation through cold dilute alkaline solutions.

In discussing the passivity of metals, E. Grave¹ states that there are serious objections to the oxide theory of passivity and to the suggestion that the passive and active metals have different valency. The author considers that Le Blanc's theory is the only one that is in accordance with facts. Le Blanc has pointed out that the solution pressure of iron in the passive state is much smaller than that in the active state, and on this basis there are two possibilities: (1) either pure iron is the active form and a negative catalyst is produced which renders it passive, or (2) pure iron is the passive form and is rendered active by some positive catalyst which greatly increases its solution pressure. The results of the author's investigations, which are given, lend support to the latter view, the positive catalyst being H⁺ ions.

H. G. Byers² and M. Darrin have shown that when iron is used as an anode in various electrolytes the current density required to produce the passive state is increased when the anode is placed in a magnetic field, and H. G. Byers³ and A. F. Morgan have now found that the same is true in the case of nickel. Magnetised steel is more difficult to render passive than steel which has not been magnetised, and soft steel is affected to a greater extent than hard steel. The positive pole of the magnets is rendered passive more easily than the negative pole.

J. Newton Friend⁴ shows that even compact forms of iron are porous, so that when the metal is immersed in certain solutions the latter are absorbed to a minute extent. The passivity induced by immersion of iron in alkaline solutions, such as those of potassium and sodium hydroxides, is due to absorption of minute quantities of these substances within the pores of the metal. The passivity may be retained for long periods if the metal is kept dry since the alkali is unable to escape. If the metal is soaked in water for several days the alkalies are washed out, and it now loses its passivity, whilst the alkalies can be detected in the washings. An explanation is thus to hand of the difficulty experienced by painters in removing all traces of acid from iron after pickling before applying the protective coatings.

Preservation of Iron and Steel.—M. A. Meade⁵ describes a system of “sand-spraying” iron or steel in order to prevent corrosion. A thin coating of silver sand is sprayed on to the paint while the

¹ *Zeitschrift für physikalische Chemie*, vol. lxxvii. pp. 513–576.

² *Journal of the American Chemical Society*, vol. xxxii. pp. 750–756.

³ *Ibid.*, vol. xxxiii. pp. 1757–1761.

⁴ *Transactions of the Chemical Society*, vol. ci. pp. 50–56.

⁵ *Journal of Gas Lighting; Foundry Trade Journal*, vol. xiv. p. 82.

latter is wet. The paint is allowed to dry, another coat is then applied, and this is also sprayed with sand. Finally, a third coat of paint is put on, but sand is not sprayed on to this. When the whole has thoroughly dried, the sand combines with the paint and forms a hard shell, which is able to withstand attacks of rust-producing agents. The apparatus for spraying the sand consists of a pair of bellows, a tin sand reservoir, and a small gas cock. The pipe from the reservoir leads into the blowpipe of the bellows, and a fan-shaped "spreader" is fitted to the bottom of the blowpipe. At the base of the reservoir is placed a gauze, which prevents the possibility of small lumps stopping up the feed-pipe; and to the underside of the reservoir lid is fitted a small flap-valve, which prevents the sand from being blown out at the top during the operation of spraying. It is recommended that the article to be treated should be thoroughly scraped and brushed with a wire brush, and a coat of red lead paint applied, without the sand spray, before the painting as suggested is commenced.

E. Liebreich¹ and F. Spitzer have carried out experiments with various iron varnishes with a view to ascertaining the influence of painting on the rusting of iron, and they find that one coat of varnish or paint may protect the iron, but that the application of several coats will actually promote rusting. Highly polished sheet-iron was coated with various paints, consisting of linseed oil and some oxide (lead, zinc, iron), sometimes further mixed with carbon; the addition of carbon made no difference in their behaviour. These sheets were suspended over boiling water for four days and nights. Half the surface of the iron was then bared of its coating with the aid of toluene, and the bare surface covered with vaseline to prevent any further rusting. In all cases except one the iron had remained bright when one coat had been applied, but had rusted under two coats, and distinctly rusted still more under three or four coats of the same paint. Some commercial paints gave the same results. Potential differences were observed between iron wires coated with the paints in question and the bare iron wire, when both wires were dipped in salt solution.

Galvanising Iron and Steel.—A. Sang² deals exhaustively with the galvanising of iron and steel. He commences by pointing out the advantages of zinc as a protective covering. Its principal competitor is tin, and, as the melting point is lower than that of zinc, its application to iron by heating processes, that is to say by dipping into the molten metal, requires a lower expenditure of fuel. The oxidation of the surface of the metal is less pronounced, and the coating is more brilliant and nicer looking than zinc, while, when used for cooking utensils, the salts of tin which may be formed are less injurious than the products of zinc. But in spite of these advantages, its high price, and the inadequacy of the protection it affords, lead to preference for

¹ *Zeitschrift für Elektrochemie*, vol. xviii. pp. 94-99.

² *Revue de Métallurgie, Mémoires*, vol. ix. pp. 1-31, 78-111, 160-186, 275-293.

zinc. Taking the relative prices of tin and zinc and the differences of density of the two metals, a coating of equivalent thickness is 7.3 times more protective when zinc is used than when tin is employed. Nickel, the price of which is about 35 per cent. higher than that of tin, can only be used in extreme cases where expense need not be considered. Copper and brass give rise to toxic products, and afford no protection against galvanic action. Lead can only be employed to a limited extent, as its adhesion to iron is poor. It offers no protection against galvanic action, but rather accelerates it, and it wears off rapidly. Coating iron and steel electrolytically by means of aluminium, although a British patent dates from 1855, is hardly a practical proposition. The Schumann process was employed some years ago to cover 500 tons of castings in the city of Philadelphia. In this case the iron was first coated with electrolytic copper, but subsequently by a layer of an alloy of tin and aluminium, but the actual coating consisted mainly of tin. The experiment gave bad results, as the coating peeled off and the iron rusted rapidly. The adhesion of pure aluminium to iron is very poor. The advantages of zinc are considered in respect to its adhesive properties, the uniformity of the coating, the absence of discontinuity, its resistance to corrosive agents and to wear, and its flexibility. The permanence of the adhesion depends on the difference between the coefficients of dilatation of the two metals. Electric processes are much superior to hot dipping in securing uniform thickness, but from the point of view of pinholing and discontinuity, electrolytic depositions are inferior to hot dipping. Although zinc is a soft metal like tin, it becomes hard after being applied to iron, this hardening being due to the absorption of the iron, which may reach as much as 8 per cent. To this extent it loses its flexibility, and special precautions are necessary when it is required that the galvanised material should be folded. A badly adhering coat of zinc highly charged with iron is one of the worst coverings that can be employed. The theory and practice of galvanisation are discussed at length, with special reference to the holds of steamers and of boiler-plates. The origin, sources, and physical and chemical properties are then considered in detail, and the influence of corrosive agents are fully described under the headings of atmospheric corrosion, corrosion in soft water, corrosion in sea water and in saline and alkaline solutions. The earliest experiments in galvanising iron by means of molten metal were carried out by a French chemist, Malouin, whose experiments in 1741 formed the basis of a report to the Royal Academy in the following year. He employed a bath of molten metal, and claimed that iron thus treated lasted longer and better than it did without such protection. Subsequently experiments were made, both in France and in other countries. In England and in America it has become a habit to regard the English patent granted in April 1837 to H. W. Craufurd as the earliest patent relating to hot galvanising, but this claim cannot be substantiated. Although the sherardising of iron is a comparatively recent process, the method of coating iron by cementation and heating in

zinc powders was known as far back as 1838. An English patent was granted in that year to Miles Berry for a somewhat similar method of coating copper with zinc. The choice of a method of galvanising is next considered, and the baths, furnaces, and methods of heating are described and illustrated. The subject is dealt with under the following heads: Preparation of the surfaces to be covered; composition of the bath; constitution of the cinders and mattes, management of the bath, use of fluxes; nature and appearance of the deposit; galvanising of sheets and of hollow articles; and the galvanising of wire, strips, thin sheets, and wire trellises.

The theory and mechanism of electrolysis are next considered, and the practical rules deduced from the theoretical considerations are given in detail. Illustrations are supplied of the electrical apparatus employed, and the machinery used in the electro-galvanising of tubes, wire, and small objects.

Sherardising is next described, and in this connection the physical state, chemical composition, production and redistillation of the zinc dusts are considered. The theory of the cementation of zinc and the influence of the electro-motive force of contact are considered, and the practical details of sherardising, together with the plant and materials employed, are described.

A. Sang¹ discusses the same subject elsewhere.

The Lohmannising process is described and illustrated.² It is similar to the old hot galvanising process, the chief difference being that instead of the muriatic bath, a spelter bath is employed. The material is first pickled in a bath of sulphuric acid and then dipped into the Lohmann bath, which, being composed of an acid and an amalgamated salt, further cleanses the pores and cavities, and deposits metallic salt upon the entire surface, the salt penetrating into the most minute pores and cavities. The bath is a solution of hydrochloric acid, bichloride of mercury, and sal-ammoniac. After drying, the materials are immersed in the molten protective alloy, and an amalgam or chemical union is thus formed between the amalgamating salt and the protective alloy. The junction between the iron and steel and the protective alloy is not only maintained chemically pure and free from oxides, but is mechanically intimate. It is possible to use zinc as a coating; or when extreme pliability is not needed, and a bright appearance is desired, an alloy of 10 parts of lead, 1 part of zinc, and 1 part of tin may usefully be employed.

It is stated³ that for rapid and efficacious removal of rust or scale from iron and steel, pickling with muriatic acid diluted with water should be used in the following proportions: Water, 1 gallon; 22° muriatic acid, 1 gallon. If slightly warmed the pickle works more rapidly than when cold.

¹ Paper read before the American Electro-Chemical Society; *Iron Trade Review*, vol. xlix. pp. 876-877.

² *Metallurgical and Chemical Engineering*, vol. x. pp. 253-254.

³ *Brass World, Practical Engineer*, vol. xlv. p. 355.

P. S. Brown¹ discusses recent progress in the preservation of iron and steel.

The Schoop Method of Coating Metals.—F. Loppé² gives an account of the application of the Schoop method of coating surfaces with metal. The method consists of projecting the powdered metal in the form of a high-speed current on to the objects to be plated. The deposit can either be made to adhere to the object, or it may be made so as to be detachable and to serve as a mould.

¹ *Metal Industry*, vol. x. pp. 23-24.

² *Revue de Métallurgie, Mémoires*, vol. ix. pp. 269-274.

CHEMICAL ANALYSIS.

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I.—ANALYSIS OF IRON AND STEEL.

Estimation of Carbon.—A. Kayl¹ gives a method for the rapid determination of carbon in steels, brass, and other iron alloys.

De Nolly² also gives a method for the determination of total carbon in iron, steel, brass, and ferro alloys.

Estimation of Carbon in Iron and Steel in the Electric Furnace.—H. Augustin³ describes a process for the estimation of carbon in iron and steel in the electric furnace. The process is similar to that described by Lorenz, but the sprinkling over of the iron with lead chromate cannot be recommended. It is, however, absolutely necessary to use copper oxide in the front part of the porcelain combustion tube in order to ensure complete oxidation of the carbon. The author also describes and illustrates an electric furnace in which it is possible to heat the iron at 1000° and the copper-oxide layer at 800°. The combustion is carried out in a current of purified oxygen, and after passing through drying-tubes containing sulphuric acid the carbon dioxide is absorbed in the usual soda-lime tubes.

Estimation of Oxygen.—A. S. Cushman⁴ states that three important methods of estimating oxygen in steel are: (1) Heating the sample in a stream of dry chlorine; (2) dissolving in special solvents, such as copper sulphate or bromine; (3) combustion in a stream of hydrogen. The hydrogen is generated from drillings of pure iron or "mossy" zinc with dilute hydrochloric acid, and is passed successively

¹ *Chimiste*, vol. iii. pp. 4-5.

² *Ibid.*, p. 26.

³ *Zeitschrift für angewandte Chemie*, vol. xxiv. pp. 1800-1803.

⁴ *Journal of Industrial and Engineering Chemistry*, vol. iii. pp. 372-374.

through potassium-hydroxide solution, concentrated sulphuric acid, over a roll of platinum gauze in a strongly-heated silica tube, and finally over phosphoric oxide. The finely-divided borings (20 to 30 grammes) are weighed into a platinum (or silica) boat introduced into the silica combustion tube, and after passing hydrogen through until all air has been removed the tube is rapidly heated to about 850° , and maintained at this temperature about thirty minutes, whilst the purified dry hydrogen passes at a rate of about 100 cubic centimetres per minute. The apparatus is then cooled in the stream of gas, and the tared absorption tube, which is charged with phosphoric oxide, is reweighed. A blank is first made to enable the necessary corrections to be made.

Estimation of Phosphorus.—C. Reichard¹ states that in the estimation of phosphorus in iron and steel it is proposed to limit the amount of iron taken for analysis to 1 gramme, owing to the high molecular weight of the ammonium phosphomolybdate which enables even minute quantities of phosphorus in iron and steel to yield a precipitate that can be weighed with great accuracy.

E. R. E. Müller² describes a method of determining phosphorus in pig iron and cast iron without the separation of silica.

Estimation of Silicon.—C. Reichard³ gives the following method for the estimation of silicon in iron containing much graphite. One gramme of the finely-divided iron is heated in a platinum crucible for fifteen minutes over a gas blowpipe, or for one hour over a Bunsen flame, and then dissolved in 25 per cent. hydrochloric acid. The solution is decanted from the small quantity of insoluble matter, and the latter is treated with fuming nitric acid. After the two acid solutions have been mixed together the insoluble graphite is collected on a filter, washed, and ignited in an atmosphere of oxygen. The portion of the silica remaining in the acid filtrate is estimated in the usual way.

Estimation of Sulphur.—G. Auchy⁴ gives details of a method for the estimation of sulphur by cadmium chloride, which obviates some of the errors attaching to the usual method by which such estimations are made. Four grammes of drillings are placed in an 8-oz. Erlenmeyer flask, 50 cubic centimetres of strong hydrochloric acid poured on, and the flask quickly connected with a Troilius bulb holding water, connected by a 100-cubic centimetre pipette with an 8-oz. Fresenius nitrogen bulb containing about 35 cubic centimetres of cadmium chloride solution made up as follows: First stock solution of one pound in 2000 cubic centimetres water; then 100 cubic centi-

¹ *Pharmazeutische Zentralhalle*, vol. lii. pp. 1314–1315.

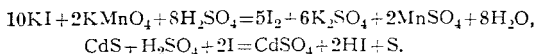
² *Chemiker Zeitung*, vol. xxxv. pp. 1201–1202.

³ *Pharmazeutische Zentralhalle*, vol. lii. pp. 939–940.

⁴ *Iron Age*, vol. lxxxviii. p. 363.

metres of this mixed with 300 cubic centimetres of strong ammonia and 600 cubic centimetres of water. After connection a low flame is applied, and when the drillings are dissolved the solution is boiled until the second small bottom bulb of the Troilius gets too hot for the fingers to grasp. The flask is then detached while still boiling, and the apparatus well blown through by the mouth. The Troilius bulb is then placed in cold water, and the pipette detached from the nitrogen flask (but not from the Troilius bulb) and placed in a small beaker. The cadmium sulphide precipitate and cadmium chloride solution are drawn up into the bulbs and kept there by a Mohr compressor clipping the rubber tube. Then into the flask thus emptied is poured a mixture of 60 cubic centimetres of dilute (1 : 1) hydrochloric acid, 115 cubic centimetres of ice water (ordinary drinking water), the bulk of the iodine solution that will be required in the titration, and a little starch solution. Then to this mixture in the nitrogen flask are transferred the contents of the Troilius bulb and pipette and of the little beaker. The contents of the bulbs at the side are run down into this liquid little by little with shaking, until the colour first changes from blue to purple. A few drops of iodine solution are then added from the burette—to restore the blue colour—and a little more of the cadmium sulphide and cadmium chloride is run down from the side bulbs, until these bulbs are emptied and the titration in them finished. The iodine solution is standardised by permanganate and thiosulphate. The titration by the thiosulphate must be made promptly in order that the sulphuric acid may not have time enough to set free any iodine.

H. Kinder¹ recommends the following method for the estimation of sulphur in iron and steel as giving both rapid and accurate results. Five grammes of drillings are dissolved in 100 cubic centimetres of warm hydrochloric acid (specific gravity, 1.19), the evolved gases being first washed in a small quantity of water to remove any free acid that distils over, and then absorbed in 50 cubic centimetres of ammoniacal cadmium chloride solution (20 grammes cadmium chloride, 400 cubic centimetres of water, and 600 cubic centimetres of ammonia, specific gravity, 0.96). The cadmium sulphide thus precipitated is filtered, washed, and transferred with the filter paper to a flask containing 10 cubic centimetres of potassium iodide solution (30 grammes potassium iodide and 10 grammes of sodium hydrogen carbonate per litre), some dilute sulphuric acid, and excess of permanganate from a burette. The whole is shaken until the cadmium sulphide is completely decomposed, and the excess of iodine is estimated with sodium thiosulphate. The reactions are:



The permanganate solution is diluted till one cubic centimetre corresponds to 0.001 gramme of sulphur.

¹ *Stahl und Eisen*, vol. xxxi. pp. 1838-1839.

E. R. E. Müller¹ describes an ingenious method of ensuring complete absorption of sulphuretted hydrogen as evolved on the solution of iron in hydrochloric acid during the estimation of the contained sulphur. The gas enters a gas jar, 6 centimetres in diameter and 14 centimetres in height, containing the cadmium solution to a depth of 9 centimetres, through a glass tube which reaches to the bottom of the jar. The end of the glass tube is twice bent at right angles, the open end being cut close off at the second bend. The gas thus leaves the tube on its upward passage through the liquid, close to the bottom and at the centre of the jar. In the centre of the jar, and dipping down some 4 centimetres into the liquid, is a bell very much like an inverted thistle funnel, but closed where it joins on to the glass tube. The rim of this bell is nicked. The bubbles of gas rise vertically through the liquid and collect in the bell. As more and more bubbles ascend the bell becomes too full, and excess gas escapes in small bubbles through the nicks in the rim. In this way the gases are exposed very thoroughly to the absorbent action of the solution in the jar.

Apparatus for the Estimation of Sulphur and Carbon.—D. A. Wennmann² finds that in the estimation of sulphur in iron and steel a continuous stream of water through which to pass the gases evolved is unnecessary. He has, therefore, devised a special cooler for the gases, which is fitted into the decomposition flask by a ground-glass joint. The whole apparatus is made of glass, and everything is so arranged that the gases evolved from the flask have to pass through water contained in the cooler before escaping to the absorption vessels. The necessary tubes for running the acid into the flask and for passing a current of carbon dioxide through the apparatus towards the end of the estimation are also provided. For the estimation of carbon a condenser is fitted into the decomposition flask by a ground-glass joint, a special tube being sealed through the bottom of the condenser for leading gases free from carbon dioxide through the apparatus. Diagrams are given.

Separation of Chromium.—J. R. Cain³ describes a method for the determination of chromium and its separation from vanadium in steels. The method is based on the fact that chromium, in much larger amounts than that carried in the ordinary commercial steels, can be precipitated completely in a few minutes by boiling the nearly neutralised ferrous solution of the steel with barium carbonate, cadmium carbonate, zinc oxide, or magnesium oxide.

Estimation of Copper.—For the estimation of copper in steels S. Zinberg⁴ states that 3 to 5 grammes of the sample are heated

¹ *Stahl und Eisen*, vol. xxxii. p. 494.

² *Zeitschrift für angewandte Chemie*, vol. xxiv. pp. 1861–1862.

³ *Journal of Industrial and Engineering Chemistry*, vol. iv. pp. 17–19.

⁴ *Zeitschrift für analytische Chemie*, vol. li. pp. 19–20.

with dilute sulphuric acid in a current of carbon dioxide. The iron dissolves, and the copper which is left unattacked is finally ignited and weighed as oxide. A special apparatus is described and illustrated.

Estimation of Manganese.—Stanichitch¹ gives a method for the rapid colorimetric estimation of manganese in iron and steel by means of ammonium persulphate. Half a gramme of the sample is heated with 20 cubic centimetres of 1·2 nitric acid in a 100 cubic centimetre flask and, after driving off the nitrous fumes, 20 cubic centimetres of silver nitrate solution (6 in 1000) are added, and while the solution is still warm about 1 gramme of ammonium persulphate is placed in the flask, which is then filled up to the 100 cubic centimetre mark with water which must be free of hydrochloric acid contamination. The thumb is placed over the mouth of the flask and the contents well shaken. The violet colour of permanganic acid appears at once. The solution is left until the maximum intensity of coloration is reached. This takes a few minutes only. An aliquot part of the solution is withdrawn and compared colorimetrically with a standard which has been similarly treated, Eggertz tubes being used. If the liquid is too hot when the silver nitrate solution is added, a slight cloudiness may arise owing to the precipitation of a little hydrated manganous oxide, and it is therefore better to cool the contents of the flask under a stream of water before adding the solution. The presence of nickel, chromium, and copper do not impair the accuracy of the results.

J. J. Boyle² gives a method for the determination of manganese in steel. This method is a modification of that of Walter, the essential difference being the introduction of sodium chloride whereby the reoxidation to permanganic acid is prevented.

Estimation of Nickel.—S. W. Parr³ and J. M. Lindgren state, with reference to the dimethylglyoxime process for the determination of nickel, that nickel may be precipitated in the presence of iron, aluminium, and chromium, provided the solution contains sufficient tartaric acid to prevent the precipitation of these metals by ammonia. In a series of determinations upon a steel containing about 1 per cent. of nickel the result afforded by direct precipitation was practically the same as that obtained by precipitation in the iron free solution. It was also found that, after precipitation with dimethylglyoxime, nickel may be determined volumetrically by dissolving the precipitate in an excess of standard sulphuric acid and titrating back with standard potassium hydroxide, the end-point being shown by the appearance of a faint yellowish colour in the previously colourless solution. The acid is standardised against pure nickel which is precipitated with dimethylglyoxime and titrated as described.

¹ *Revue de Métallurgie, Mémoires*, vol. viii. pp. 891-892.

² *Journal of Industrial and Engineering Chemistry*, vol. iv. pp. 202-203.

³ *Transactions of the American Brass Founders' Association*, vol. v. pp. 120-124.

Estimation of Tungsten.—T. Kuczyński¹ gives the following methods for the assay of high-grade alloys of tungsten:—

Chlorine Method.—The coarsely-powdered sample is placed in a porcelain boat, and introduced into a combustion tube connected with a Peligot tube filled with dilute hydrochloric acid (1:5). A rapid current of chlorine is passed, and when the air is completely expelled the combustion is started as usual until only a little carbon remains in the boat. When cold the tubes are disconnected, and after emptying the Peligot tube both are washed, first with warm hydrochloric acid and then with dilute ammonia. The mixed liquids, measuring about 500 cubic centimetres, are mixed with 5 cubic centimetres of hydrochloric and nitric acids in excess, and boiled until 60 cubic centimetres are left. The tungstic acid is then collected and washed, but as some remains in solution it is necessary to recover this by evaporating to dryness and heating the residue at 120°; the mass is then boiled with dilute hydrochloric acid, and the undissolved tungstic acid is collected. Any iron contained in the tungstic acid may be freed therefrom by dissolving in dilute ammonia and reprecipitating by boiling with excess of dilute hydrochloric acid (1:10); the traces remaining in solution are then again recovered by evaporation as directed. The precipitate is finally dissolved in ammonia, evaporated to a small volume in a quartz crucible, acidified with nitric acid, evaporated to dryness, and then ignited to the trioxide.

Hydrofluoric Acid Method.—The sample, in small lumps, is treated in a platinum crucible with 5 cubic centimetres of nitric acid (D 1.4) and 2 cubic centimetres of water for every 0.2 gramme taken for the assay; 0.5 gramme (or more) of ammonium fluoride is added, and the whole is heated on the water-bath until dissolved; sometimes it is necessary to add a few drops of sulphuric acid. Finally 2 to 3 cubic centimetres of sulphuric acid are added, and the fluorine is expelled by heating on the water-bath. When cold the contents are rinsed with water into a beaker, traces of tungstic acid adhering to the dish being dissolved in dilute ammonia. The solution, measuring about 60 cubic centimetres, is then boiled with 20 cubic centimetres of hydrochloric acid, &c., as in the chlorine method.

Mechanical Methods of Analysis.—C. H. Ridsdale² and N. D. Ridsdale give further data on the subject of mechanicalised methods of analysis, being an extension of the paper submitted by the authors to the Iron and Steel Institute.³

Laboratory Equipment.—K. Friedrich⁴ describes the buildings and equipment of the metallurgical department of the Royal

¹ *Bulletin International de l'Académie des Sciences de Cracow*, 1911, A, pp. 542-544.

² *Proceedings of the Cleveland Institution of Engineers*, 1911-1912, No. 4, pp. 149-164.

³ *Journal of the Iron and Steel Institute*, 1911, No. I. pp. 332-375.

⁴ *Metallurgie*, vol. ix. pp. 41-48, 81-92.

Technical High School at Breslau. Photographs of the various laboratories are shown.

A preliminary report on the quality of platinum laboratory utensils has been issued¹ by a committee appointed by the American Chemical Society on the occasion of the Convention at Minneapolis. The committee consisted of W. F. Hillebrand, P. H. Walker, and E. T. Allen, and the report deals with the alleged inferiority of platinum ware made in recent years compared with that procurable many years ago. The objections as to inferior ware comprise allegations as to undue loss of weight on ignition and on acid treatment, unsightly appearance, alkalinity, blistering, and the development of cracks, and a tendency of crucibles and dishes to adhere to triangles. The report deals with each of these defects.

H. L. Bowman² illustrates a form of crucible tongs which he has used for some years for handling crucibles, in analytical work. The tongs are made of stout wire coiled into a spring at the middle, and bent up at the ends to form two semi-circular jaws, which lie in a plane of 45° to the plane of the legs. They are about $6\frac{1}{2}$ inches in length, and may be made of bright iron wire of about 0.09 inch in thickness or of the bronzed wire used for sofa-springs. The springiness of the legs enables a platinum or porcelain crucible (with its lid on) to be grasped firmly without fear of damage, while the oblique position of the jaws permits it to be readily lowered into a desiccator or inserted through the door of a balance-case.

A description has appeared³ of the equipment of the Harrison-Hughes Engineering Laboratories of the Liverpool University.

II.—IRON ORES AND SLAGS.

Sampling of Ores.—It is by no means easy to obtain thoroughly representative samples of ores for chemical analysis from large amounts of raw material. W. Schafer⁴ draws attention to this in connection with the analysis of iron ores where, in the case of a 10,000-ton order the difference of 1 per cent. of iron may raise or lower the value of the load by £200. Generally speaking it is easier correctly to sample a roughly-powdered ore than one occurring in large lumps. In sampling, not less than 2 lbs. of ore should be taken per ton, and the sampling may conveniently be done whilst the ore is being unloaded. If the ore is a mixture of large, small, and very small pieces a rough estimate of the relative proportions may be made and a proportionate weight of sample of each kind taken, mixed together, and analysed.

¹ *Metallurgical and Chemical Engineering*, vol. ix. pp. 649-651.

² *Chemical News*, vol. cv. p. 169.

³ *Engineer*, vol. cxiii. pp. 516, 533-535.

⁴ *Stahl und Eisen*, vol. xxxii. pp. 53-55.

Estimation of Iron.—A. Wencelius¹ gives a modification of Reinhardt's method for the titration of iron by potassium permanganate, which is specially suitable for use with ores of the minette type. Anomalies occur in using this method owing to the permanganate solution being standardised with pure solutions, whereas it should be standardised with a solution resembling that with which it is intended to be used. The modification consists, therefore, in preparing a sample of minette ore for the purpose of standardisation.

Estimation of Carbon in Ferro-Chromium.—F. Gereke² and N. Patzukoff describe a rapid method of estimating carbon in ferro-chromium. The ferro-chromium is reduced to a fine powder in an agate mortar and 0.2 gramme taken and mixed with about 2 grammes of sodium peroxide in a porcelain crucible of 20 cubic centimetres capacity. This is then placed inside a larger iron or nickel crucible, which rests on a perforated asbestos plate, and is heated over a Bunsen flame for about ten minutes until dark red in colour. The mixture melts quietly without spluttering, but if other proportions of ferro-chromium and peroxide are taken the reaction is often violently explosive. The mixture is then cooled in a desiccator, and the porcelain crucible is introduced into a wide-mouthed flask fitted with a double-bored rubber stopper, carrying two glass tubes, one of which reaches almost to the bottom of the flask, whilst the other merely pierces through the stopper. The short tube is connected to a soda-lime tube, and hot distilled water is added through the long tube to dissolve out the contents of the crucible. The flask is raised to boiling to decompose the sodium peroxide. The short tube is now connected with a drying tube containing sulphuric acid and a weighed soda-lime tube. Air free from carbon dioxide is aspirated through the long tube into the flask, and out through the short tube and its connections. Sulphuric acid (1 : 1) is now added to the flask, drop by drop, by a funnel attachment to the long tube, and the evolved carbon dioxide passes with the aspirated air into, and is absorbed by, the weighed soda-lime tube. A blank experiment must be done in a similar manner with the sodium peroxide alone.

Separation of Iron and Manganese.—J. A. Sanchez³ gives the following method for the quantitative separation of iron from manganese: Pyridine is added to a slightly acid solution of the ferric and manganous salts until no further precipitation takes place, the mixture being then boiled for ten minutes and filtered. The precipitated ferric hydroxide is washed with a hot saturated aqueous solution of pyridine and then with boiling water. Precipitation of the iron is complete, whilst all the manganese remains in solution. With relatively large quantities of manganese, however, it is advis-

¹ *Bulletin de la Société de l'Industrie de l'Est*, No. 87, p. 14.

² *Stahl und Eisen*, vol. xxxii, pp. 439-440.

³ *Bulletin de la Société Chimique de France*, vol. ix, pp. 880-881.

able to dissolve the precipitate in hydrochloric acid and re-precipitate. Metals precipitated by hydrogen sulphide from acid solutions should preferably be first removed. If zinc be present the ferric hydroxide must be dissolved and re-precipitated with ammonium chloride and ammonia.

Estimation of Manganese.—In discussing the bismuthate method for the determination of manganese, D. J. Demorest¹ states that if the permanganic acid solution obtained by the oxidation with bismuthate be titrated directly with sodium arsenite solution, any chromic or vanadic acid which may be present has no influence on the results.

P. H. M.-P. Brinton² states that the factor 0.16397 represents the ratio $5\text{Na}_2\text{C}_2\text{O}_4 : 2\text{Mn}$, and not 0.16024 as given in his previous article. This mistake does not influence the correctness of the empirical factor 0.1656 suggested by the author, although it diminishes the necessity for its employment, neither does it affect the analytical results described in the previous communication.

P. Slawik³ describes a method for the rapid determination of manganese in ferro-tungsten. A gramme of the powdered alloy is fused in a porcelain crucible with 10 grammes of sodium dioxide, finally being kept at red heat for a few minutes. The fusion is dissolved in water, acidified with hydrochloric acid in large excess, and the solution boiled for twenty minutes. A slight excess of zinc oxide is added, and the manganese titrated with potassium permanganate by the Vollhard method. No injurious substances are extracted from the porcelain crucibles, which last for three to five fusions.

Preparation of Iron and Manganese Arsenides.—S. Hilpert⁴ and T. Dieckmann describe iron and manganese arsenides and the method of their preparation.

Estimation of Silica.—F. Moldenhauer⁵ states that in order to obtain accurate estimations of silica in iron ores it is advisable to use platinum dishes, as it is often impossible to remove the silica, rendered insoluble by evaporation, from porcelain basins.

Estimation of Sulphur.—C. Davis⁶ and J. L. Foucar describe a method devised by the former for the rapid estimation of free sulphur in spent oxide, which comprises the treatment of finely powdered and dried material with a solution of sodium cyanide in absolute alcohol, the resulting sulphocyanide being titrated in the usual way. The

¹ *Journal of Industrial and Engineering Chemistry*, vol. iv. p. 19.

² *Ibid.*, vol. iii. p. 376.

³ *Chemiker Zeitung*, vol. xxxvi. p. 106.

⁴ *Berichte*, vol. xlv. pp. 2378-2385.

⁵ *Zeitschrift für analytische Chemie*, vol. l. pp. 754-755.

⁶ *Journal of the Society of Chemical Industry*, vol. xxxi. p. 100.

results obtained are quite sufficiently accurate for commercial purposes.

A. Heczko¹ gives details of experiments carried out in order to compare the methods of Dennstedt and Lunge for the determination of sulphur in pyrites.

Estimation of Calcium Oxide.—A rapid method for the estimation of calcium oxide is given by L. W. Bahney.² 0·6 gramme of the finely ground sample is well shaken in an Erlenmeyer flask with 50 cubic centimetres of distilled water, 2 drops of phenolphthalein added, and the mixture titrated with standard oxalic solution until the vivid pink colour disappears. If a complete titration is allowed to stand for fifteen to thirty minutes, the pink colour will return and show as brightly as possible. The reading of the burette is in percentages of calcium oxide. The solutions necessary are: oxalic acid, 14·6068 grammes per litre; phenolphthalein, 0·5 gramme dissolved in 50 cubic centimetres of alcohol and 50 cubic centimetres of water.

Ferro-Boron.—R. S. Davis³ describes a method for the analysis of ferro-boron.

Analysis of Titaniferous Iron Ores.—W. Manchot⁴ and B. Heffner have examined two specimens of titaniferous iron ores—(I) a coarse ore from Ekersund, and (II) a large crystal of ilmenite from Ural, with a view to ascertaining whether such ores have the constitution FeO , TiO_2 or Fe_2O_3 , Ti_2O_3 . The titanium is estimated by fusion with potassium hydrogen sulphate, reduction of the iron with sulphurous acid, and precipitation of titanous acid by boiling. The total iron is estimated in a solution reduced by sulphurous acid, and the ferric iron iodometrically in a solution prepared by means of hydrochloric acid in absence of air:—

	Ti.	Total Fe.	Fe."	Mg.	Ca.	S.
I.	16·12	44·50	22·76	0·66	0·25	0·28
II.	29·81	34·71	9·38	...	...	0·08

The ratio $\text{Ti} : \text{Fe}'' : \text{Fe}'''$ is, for I., 1 : 1·1147 : 1·125, and for II., 1 : 0·7312 : 0·2706.

The ferric iron in II. is probably due to secondary oxidation, and the ratio $\text{TiO}_2 : \text{FeO}$ thus approaches 1 : 1 in both cases. Although it has been shown that compounds containing trivalent titanium evolve hydrogen with alkalis, hydrogen is not evolved by the action of alkalis on ilmenite. The reaction of ilmenite with sulphuric acid is also quite similar to that of a mixture of titanous acid and a ferrous salt. The conclusion is drawn that titaniferous iron ores contain only titanium dioxide, and not titanous compounds.

¹ *Zeitschrift für analytische Chemie*, vol. i. pp. 748–753.

² *Bulletin of the American Institute of Mining Engineers*, 1911, pp. 895–899.

³ *Metallurgical and Chemical Engineering*, vol. ix. p. 458–459.

⁴ *Zeitschrift für anorganische Chemie*, vol. lxxiv. pp. 79–85.

Estimation of Titanium.—A. Gautier¹ gives a calorimetric method for the estimation of titanium in clayey ores. The process is based on the property possessed by hydrogen peroxide of imparting an orange-red tint to a solution of titanous oxide in a sulphuric acid solution, the depth of colour being proportional to the amount of oxide present. As the colour fades the standard should be prepared freshly once a week. A more constant standard may be obtained by the use of a 2 per cent. solution of helianthine dissolved in cold water.

Estimation of Tungsten.—W. Trautmann² states that for the estimation of tungsten in wolframite in the presence of molybdenite, 1 gramme of finely powdered ore is gently roasted in a platinum crucible until the odour of sulphur dioxide has disappeared. The mass is then extracted three or four times with warm dilute ammonia, which dissolves the molybdenum trioxide formed. The filter, after being washed with solution of ammonium nitrate, is replaced in the crucible, and the whole is again ignited. The residue is then submitted to the ordinary fusion with sodium hydroxide, which should be carried out in a nickel crucible.

Estimation of Vanadium.—D. J. Demorest³ describes a new method for the estimation of vanadium.

III.—ANALYSIS OF FUEL.

Sampling Coal, Coke, and Tar.—An account is given⁴ of the best methods of obtaining representative samples of coal, coke, and tar for analytical purposes. In sampling tar in cisterns care must be taken to remove portions from various depths, as the general composition and water-content of the tar varies at different levels. For this purpose a movable tube, 5 to 10 centimetres in diameter, is recommended.

Sampling of Coal.—An illustrated description is given⁵ of a mechanical laboratory coal sampler used by the Philadelphia and Reading Coal and Iron Company.

In a memorandum to the Manchester Steam Users' Association, C. E. Stromeyer⁶ deals with the sampling of coal.

In order to avoid the mechanical loss which takes place in the

¹ *Revue générale de Chimie pure et appliquée*, vol. xiv. pp. 14-16.

² *Zeitschrift für angewandte Chemie*, vol. xxiv. pp. 2142-2143.

³ *Journal of Industrial and Engineering Chemistry*, vol. iv. pp. 249-250.

⁴ *Stahl und Eisen*, vol. xxxi. p. 1556.

⁵ *Mines and Minerals*, vol. xxxii. p. 139.

⁶ *Practical Engineer*, vol. xlv. pp. 781-782.

determination of volatile matter in coals, especially in lignite and Illinois coals, S. W. Parr¹ recommends that the sample of coal (1 gramme) should be saturated with 10 to 15 drops of kerosene.

A. Meurice² deals with sampling and the determination of humidity, ash, volatile matter, and sulphur in coke and gas coal.

J. Lomax³ discusses the microscopical examination of coal and its use in determining the inflammable constituents present.

Determination of Sulphur in Petroleums.—J. M. Sanders⁴ considers that the Mahler or Hempel calorimetric bomb method for estimating the total sulphur in petroleums, although trustworthy, is somewhat lengthy, and he describes a method by which a large sample may be concentrated by treatment with fuming nitric acid and potassium bromide, the product being absorbed by magnesium oxide, which enables it to be readily removed from the concentrating dish and burnt in the Parr apparatus with sodium peroxide. Several samples may be treated simultaneously, the final combustion taking about forty-five seconds.

D. Lohmann⁵ describes a method for the determination of sulphur in petroleum.

IV.—ANALYSIS OF GAS.

Analysis of Gases in Ironworks Practice.—H. Naegell⁶ discusses, in a theoretical manner, the methods of calculating and expressing the quantitative analysis of gaseous mixtures such as are dealt with in blast-furnace and foundry practice.

Apparatus for Analysis of Furnace Gases.—J. C. W. Frazer⁷ and E. J. Hoffmann describe apparatus and methods for the sampling and analysis of furnace gases.

Estimation of Carbon Monoxide.—L. A. Levy⁸ gives the following method for the estimation of carbon monoxide, which is based on Gautier's anhydride method. The gaseous mixture is drawn by means of an aspirator through a solution of bromine in potassium bromide to fix unsaturated hydrocarbons, and then through aqueous potassium hydroxide (1:1) to remove bromine vapours, and also any carbon dioxide. After removing aqueous vapours by passing the gas

¹ *Journal of Industrial and Engineering Chemistry*, vol. iii. pp. 900-902.

² *Annales des Mines de Belgique*, vol. xvi. pp. 553-577.

³ Paper read before the North Staffordshire Institute of Mining and Mechanical Engineers, January 29, 1912.

⁴ *Proceedings of the Chemical Society*, vol. xxvii. pp. 329-330.

⁵ *Chemiker Zeitung*, vol. xxxv. pp. 1119-1120.

⁶ *Stahl und Eisen*, vol. xxxii. pp. 617-618.

⁷ *United States Bureau of Mines, Bulletin No. 12*, pp. 3-22.

⁸ *Journal of the Society of Chemical Industry*, vol. xxx. pp. 1437-1440.

over phosphoric oxide, the carbon monoxide is oxidised to carbon dioxide by passing it through a U-tube filled with a mixture of asbestos and iodic anhydride, and heated in an air-bath at 160° to 180° ; to the U-tube is sealed another one filled with copper turnings, which completely absorb the iodine liberated. The carbon dioxide is now absorbed, in a specially constructed apparatus resembling a Winkler coil, in a known volume of standard solution of barium hydroxide coloured with phenolphthalein, and the operation is continued until the liquid is decolourised; a simple calculation then gives the carbon monoxide. When the amount of carbon monoxide is but very small, the excess of baryta may be titrated with oxalic acid after a certain volume of the gas has passed through without waiting for decolourisation.

Estimation of Carbon Dioxide in Smoke.—An apparatus is illustrated and described¹ by means of which carbon dioxide may readily be estimated in smoke and furnace gases.

Nomenclature of the Oxides of Carbon.—C. Hering² advocates the abandonment of the terms carbonic oxide and acid, and points out that the consistent applications of the terminations *-ous* and *-ic* would necessitate the lower or monoxide of carbon, CO, being, for consistency's sake, called carbonous oxide, and the higher or dioxide CO₂, carbonic oxide. The use of the term carbonic oxide for the lower oxide is indefensible, and there should be no objection to using the term carbonous oxide for CO, as there should be no confusion, and the nomenclature would then be consistent with that used for other elements.

Analysis of Mine Gas.—G. A. Burrell³ gives the results of analyses of a number of samples of mine gases collected under different conditions, that is, after firing explosives, after fires, and after explosions. In most cases they show the presence of injurious amounts of carbon monoxide.

Atomic Weight of Nitrogen.—E. Wourtsel⁴ states that five experiments have given for the atomic weight of nitrogen the values 14.005, 14.008, 14.006, 14.007, 14.008; mean 14.007. The method employed involved determination of the weight of oxygen necessary to convert a known weight of nitric oxide into nitric peroxide. A U-tube containing cooled liquid nitric peroxide as a solvent was weighed, and a definite weight of nitric oxide passed in. Pure dry oxygen was then introduced, and the increase in weight determined, after removing excess of oxygen by evacuating the apparatus at the temperature of liquid air.

¹ *Stahl und Eisen*, vol. xxxii. p. 245.

² *Metallurgical and Chemical Engineering*, vol. ix. p. 625.

³ *Journal of Industrial and Engineering Chemistry*, vol. iv. pp. 96–100.

⁴ *Comptes Rendus*, vol. cliv. pp. 115–116.

STATISTICS.

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I.—UNITED KINGDOM.

Mineral Statistics.—The production of iron ore in 1911, apart from that obtained in quarries, was 9,710,693 tons, of which 7,886,898 tons were mined under the Coal Mines Act, and 1,823,795 under the Metalliferous Mines Act. The output of coal in 1911 was 271,878,924, as against 264,417,588 tons in 1910, showing an increase of 7,461,336 tons. The output of other minerals included 4987 tons of manganese ore, 2,482,846 tons of fireclay, 17,149 tons of limestone, 3,116,803 tons of oil shale, 6007 tons of bauxite, and 260 tons of tungsten ore. The number of persons employed at mines under the Coal Mines Act was 1,067,213, an increase of 17,806.¹

Iron Trade Statistics.—According to the British Iron Trade Association,² the production of pig iron in Great Britain in 1911 was 9,718,638 tons, as compared with 10,216,745 tons in 1910 and 9,664,287 tons in 1909.

The total amount of steel produced in 1911 amounted to 6,461,612 tons. The following table shows the figures of output for Bessemer

¹ *Mines and Quarries: General Report and Statistics for 1911.* (Advance proof.)

² *Iron and Coal Trades Review*, vol. lxxxiv. pp. 771, 799.

and open-hearth steel ingots, distinguishing basic and acid, for the years 1885 to 1911 :—

Year.	Acid.		Basic.		Total Acid.	Total Basic.	Total Bessemer.	Total Open- Hearth.
	Bessemer.	Open- Hearth.	Bessemer.	Open- Hearth.				
	Tons.	Tons.	Tons.	Tons.				
1885	...	...	...	...	1,734,307	145,707	...	...
1886	...	...	...	...	2,007,037	258,466	...	...
1887	...	...	...	...	2,682,093	364,526	...	...
1888	...	...	...	...	2,898,143	408,594	...	...
1889	1,719,292	1,357,461	422,211	71,708	3,076,753	493,919	2,141,503	1,429,169
1890	1,612,730	1,462,913	402,133	101,287	3,075,643	503,420	2,014,863	1,564,200
1891	1,396,229	1,414,052	335,776	100,486	2,720,281	436,262	1,642,005	1,514,538
1892	1,202,000	1,310,774	298,783	108,056	2,512,774	406,839	1,500,783	1,418,830
1893	1,260,992	1,377,664	262,362	78,645	2,608,656	341,007	1,523,554	1,456,309
1894	1,139,611	1,470,787	395,753	104,531	2,610,398	500,284	1,535,364	1,575,318
1895	1,093,675	1,564,868	441,550	159,869	2,658,543	601,419	1,533,225	1,724,737
1896	1,357,580	2,145,268	457,262	172,287	3,502,848	629,549	1,814,842	2,317,555
1897	1,374,339	2,393,918	509,816	203,088	3,768,257	717,904	1,884,155	2,602,006
1898	1,255,252	2,590,512	504,134	216,088	3,845,764	720,026	1,759,886	2,806,600
1899	1,307,696	2,735,563	517,378	294,688	4,043,259	812,066	1,825,074	3,030,251
1900	1,253,903	2,862,566	491,107	293,484	4,116,469	784,585	1,745,004	3,136,050
1901	1,115,985	2,946,614	490,268	351,177	4,062,599	841,445	1,606,253	3,297,791
1902	1,157,380	2,676,508	668,399	406,780	3,833,888	1,075,179	1,825,779	3,083,288
1903	1,316,915	2,613,274	593,103	510,809	3,930,189	1,103,912	1,910,018	3,124,083
1904	1,129,224	2,583,282	652,309	662,064	3,712,506	1,314,373	1,781,533	3,245,346
1905	1,396,233	3,042,834	577,977	795,238	4,439,067	1,373,215	1,974,210	3,838,072
1906	1,307,149	3,378,691	609,189	1,176,245	4,685,840	1,776,434	1,907,338	4,554,936
1907	1,280,315	3,384,780	578,944	1,278,709	4,665,095	1,857,653	1,859,259	4,663,489
1908	906,466	2,578,840	572,073	1,238,263	3,485,306	1,810,336	1,478,539	3,817,103
1909	1,111,042	2,763,158	622,178	1,385,250	3,874,200	2,007,428	1,733,220	4,148,408
1910	1,138,103	3,016,830	641,012	1,578,536	4,154,933	2,219,548	1,779,115	4,595,366
1911	837,767	3,131,118	573,373	1,869,354	4,018,885	2,442,727	1,461,140	5,000,472

The production of Bessemer steel rails (including sleepers and fish-plates) in the United Kingdom in 1911 was 583,490 tons, as compared with 711,915 tons in 1910. The output of Bessemer finished and semi-finished products in 1911 was as follows :—

	Tons.
Blooms, billets, and slabs	142,161
Steel and tinplate bars	316,891
Sleepers and fishplates	66,992

The total output of manufactured open-hearth steel in 1911 amounted to 4,480,450 tons, as compared with 4,089,668 tons in 1910. The production of open-hearth steel rails in 1911 was 253,035 tons.

The production of puddled iron in the United Kingdom in 1911 was 1,191,499 tons, being an increase of 72,606 tons on the output of 1910. The amount of mild steel produced in 1911 was 906,957 tons, while the production of finished iron amounted to 1,097,250 tons.

II.—AUSTRALASIA.

Mineral Statistics of New South Wales.—The coal output of New South Wales in 1911 amounted to 8,691,604 tons, as against 8,173,508 tons in 1910. The output of coke in 1911 was 264,687 tons. There was also produced 283 tons of tungsten.¹

Iron Trade Statistics of New South Wales.—The production of iron and steel, made from ores mined in the State during 1911, was as follows² :—

	Tons.
Pig iron	24,658
Puddled bar-iron	1,789
Steel	2,633

Mineral Statistics of Western Australia.—The production of coal³ in Western Australia in 1910 amounted to 262,166 tons, being the record output to date.

III.—AUSTRIA-HUNGARY.

Mineral Statistics.—During the year 1911 the output of coal in Austria⁴ amounted to 14,861,314 tons, as against 13,773,985 tons in 1910. Of the total the Ostrau-Karwin district contributed over one half. The manufacture of coal briquettes amounted to 138,838 tons in 1911, and the make of coke was 2,076,978 tons. The output of lignite last year totalled 25,255,429 tons, or 122,000 tons more than in 1910. The manufacture of lignite briquettes showed an increase, being 208,759 tons, as against 186,146 tons in 1910.

Mineral Statistics of Hungary.—The production of lignite in Hungary during 1910⁵ was 7,734,166 tons, the production of bituminous coal during that year having been 1,302,103 tons. The production of iron ore in the same period was 1,905,749 tons, and 13,370 tons of manganese ore were also produced. The bulk of the lignite was obtained from the Zsil Valley and the bulk of the coal from Pécs. The number of workmen employed in the mining industry in Hungary in 1910 was 75,674.

¹ *New South Wales, Department of Mines, Annual Report for 1911.*

² *Ibid.*

³ *Western Australia, Department of Mines, Report for the Year 1910.*

⁴ *Oesterreichische Zeitschrift*, vol. lx. p. 94; *Iron and Coal Trades Review*, vol. lxxxiv. p. 169.

⁵ *Annuaire Statistique pour l'Année 1910.* Published by the Central Bureau of Statistics for the Kingdom of Hungary. Budapest, 1911.

Iron Trade Statistics.—Recently available figures relating to the production of pig iron in Austria-Hungary in 1910¹ show that during the year there were produced 1,967,000 tons. The exports amounted to 21,000 tons and the imports 102,000 tons, while the home consumption was 2,048,000 tons. Of the production in 1910, Austria contributed 1,475,000 tons, comprising 1,216,000 tons of Bessemer and forge pig, and 259,000 tons of foundry pig, while Hungary contributed 492,000 tons, comprising 477,000 tons of Bessemer and forge pig, and 15,000 tons of foundry pig.

The output of semi-manufactured iron and steel in 1911 in Austria, Hungary, and Bosnia (including Herzegovina)² totalled 2,435,757 tons, comprising 2,348,294 tons of various descriptions of steel ingots and castings, and 87,463 tons of puddled iron and steel. Details of the production are as follows:—

Steel Ingots and Castings.

	Tons.
Bessemer ingots and castings { Acid . . .	34,358
{ Basic . . .	293,700

Open-hearth Ingots and Castings.

Acid and basic	1,979,902
Crucible steel	17,467
Electric steel	22,867

Total	<u>2,348,294</u>
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Puddled Iron and Steel.

	Tons.
Puddled steel (not included in ingots) . . .	14,714
Puddled iron	72,749

Total	<u>87,463</u>
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The output of the works of the Austro-Hungarian Iron and Steel Syndicate³ during the year 1911 was as follows:—

	1911. Tons.
Bars and shapes	414,000
Joists	159,500
Plates and sheets	46,800
Rails	67,800
Total	<u>688,100</u>

IV.—BELGIUM.

Mineral Statistics.—The output of coal in Belgium during the year 1911⁴ amounted to 23,125,140 tons, being 792,000 tons short of the production in 1910.

¹ *Iron and Coal Trades Review*, vol. lxxxiv. p. 767.

² *Comité des Forges de France, Bulletin* No. 3084; *Iron and Coal Trades Review*, vol. lxxxiv. p. 614.

³ *Iron and Coal Trades Review*, vol. lxxxiv. p. 245.

⁴ *Comité des Forges de France, Bulletin* No. 3113; *Iron and Coal Trades Review*, vol. lxxxiv. p. 243.

Iron Trade Statistics.—The production of pig iron in Belgium during 1911¹ amounted to 2,106,120 tons, of which 1,964,100 tons were basic and Bessemer, 90,950 tons forge, and 51,070 tons foundry. Of the furnaces existing at the end of 1911 there were 44 in blast, as compared with 39 at the end of 1910, and 6 out of blast.

The production of steel in Belgium² during 1910 amounted to 1,944,820 tons, and comprised the following :—

	Tons.
Steel castings	52,660
Bessemer	1,755,500
Open-hearth	136,660

The following table shows the production of finished steel in 1911 :—

	Tons.
Merchant shapes	324,390
Steel sections	114,860
Rails and sleepers	347,890
Shafts and axles	31,860
Girders	168,000
Wire rods, &c.	121,200
Thick sheets	45,660
Steel stampings	1,880
Total	<u>1,155,740</u>

V.—CANADA.

Mineral Statistics.—According to preliminary statistics prepared by J. McLeish³ the total production of coal in Canada in 1911 amounted to 11,291,553 short tons.

The total production of oven coke in 1911 was 847,402 tons, as compared with 902,715 tons in 1910.

A further falling off is shown in the output of petroleum, the production in 1911 being 291,092 barrels as compared with 315,895 barrels in 1910.

Mineral Statistics of British Columbia.—According to the preliminary review and estimate of the mineral production of British Columbia in 1911, compiled by W. F. Robertson,⁴ the output of coal was 2,435,000 tons, as against 2,800,046 tons in 1910. The make of coke was 77,500 tons in 1911, as compared with 218,029 tons in 1910.

Iron Trade Statistics.—J. McLeish⁵ further reports that the total production of pig iron in Canada in 1911 was 917,535 short tons. Of the total, 20,758 tons were made with charcoal as fuel and 896,777 tons with coke. The classification of the production in 1911 was as

¹ *Moniteur des Intérêts Matériels; Iron and Coal Trades Review*, vol. lxxxiv. p. 102.

² *Annales des Mines de Belgique*, vol. xvi. No. 4, Table No. 8.

³ *Canada, Department of Mines, Mines Branch, Ottawa, 1912, Report No. 150.*

⁴ *Iron and Coal Trades Review*, vol. lxxxiv. p. 449.

⁵ *Canada, Department of Mines, Mines Branch, Ottawa, 1912. Report No. 150.*

follows: Bessemer, 208,626 tons; basic, 464,220 tons; foundry and miscellaneous, 244,686 tons.

The production of steel ingots and castings in 1911 was approximately as follows:—

	Tons.
Steel ingots—Open-hearth (basic)	651,676
„ Bessemer (acid)	209,817
Castings—Open-hearth	13,982
Other steel	740
Total	<u>876,215</u>

From statistics collected by the American Iron and Steel Association¹ it appears that the production of all kinds of pig iron in Canada in 1911 amounted to 824,345 tons, against 740,210 tons in 1910, an increase of 84,135 tons, or over 11·3 per cent. The production in 1911 was much the largest in the history of the Dominion. Of the total production in 1911, 799,716 tons were made with coke, and 24,629 tons with charcoal, coke, and by electricity, &c. In the following table the production of pig iron in Canada in the last eighteen years is given. Spiegeleisen and ferro-manganese are included. For all these years the statistics given have been compiled by the American Iron and Steel Association.

Year.	Tons.	Year.	Tons.
1894	44,791	1903	265,418
1895	37,829	1904	270,942
1896	60,030	1905	468,003
1897	53,796	1906	541,957
1898	68,755	1907	581,146
1899	94,077	1908	563,672
1900	86,090	1909	677,090
1901	244,976	1910	740,210
1902	319,557	1911	824,345

Of the total in 1911 the production of basic pig iron amounted to 413,303 tons, and the production of Bessemer pig iron to 186,274 tons; the remaining 224,768 tons being chiefly foundry iron. On December 31, 1911, Canada had eighteen completed blast-furnaces, of which twelve were in blast and six idle. Of the furnaces in blast, one was operating on charcoal. Of the eighteen furnaces in existence fourteen usually use coke for fuel and four use charcoal. In addition two coke furnaces were being built on December 31. In 1911 the Canadian furnaces consumed 1,565,877 tons of iron ore and 41,427 tons of mill cinder, scale, and turnings. The average consumption of iron ore, mill cinder, and scale in 1911 per ton of pig iron made was 1·94 tons.

VI.—CHINA.

Iron Trade Statistics.—G. E. Anderson² gives particulars relating to the production of iron and steel in China in 1910. The

¹ *Bulletin of the American Iron and Steel Association*, vol. xlv. pp. 18, 37.

² *Ibid.*, p. 4.

only modern steelworks in China which produce iron and steel upon a commercial basis, are the Hanyang Iron and Steelworks, near Hankow. This plant produced in 1910, 130,000 tons of pig iron and 33,248 tons of steel rails and fastenings. Of the pig iron made in 1910, 14,034 tons were shipped to Shanghai and other points, 29,167 tons to Japan, and 15,100 tons to the United States.

VII.—FRANCE.

Mineral Statistics.—The output of coal and anthracite in France¹ in 1911 amounted to 38,643,561 tons, and the production of lignite was 706,480 tons.

The production of iron ore in France in 1910 amounted to 14,046,982 tons.²

Iron Ore in French and German Lorraine.—A. Guillin³ deals with the production and consumption of iron ore in German and French Lorraine. The oolitic iron ore deposits, usually known as minette, occupy the west of the Moselle, the largest area being in France. The ore is specially suitable for the manufacture of steel by a basic Bessemer process. This process, although invented in England, is even more suitable for the treatment of the minette ores of Lorraine than for the Cleveland ore, for which it was originally designed. The importance of the deposits is shown by the fact that in 1910 German Lorraine produced 2,687,000 tons of pig iron; Meurthe et Moselle, 2,773,000 tons; Luxemburg, 1,682,000 tons; the Sarre district, 1,198,000 tons; Belgium, 1,803,000 tons; and Westphalia, 6,515,000 tons. The pig iron produced in German Lorraine, in the Meurthe et Moselle district, and in Luxemburg is made wholly from minette. Except for a small proportion, which is made from Spanish ores, the Belgian production is also chiefly from the minette ores; while in Westphalia, 67 per cent. of the output is basic pig made from minette ores. Prospects of fresh developments of the iron ore resources of the district are exceedingly promising. This specially applies to the ores of Briey, which are richer in iron and in calcium than the ores of German Lorraine and Luxemburg.

The quantities of ore available have been variously estimated from time to time. Twenty years ago it was believed that the German area was richest; the recent researches have, however, demonstrated that the contrary is the case.

¹ *Comité des Forges de France, Bulletin* No. 3093; *Iron and Coal Trades Review*, vol. lxxxiv, p. 575.

² *Comité des Forges de France, Bulletin* No. 3111.

³ *Revue de Métallurgie, Mémoires*, vol. viii, pp. 748-785.

Kohlmann gives the following figures for the Meurthe et Moselle district :—

	Millions of Tons.
Nancy	300
Longwy	300
Briey	2000
Crusnes	600
Total	<u>3200</u>

This relates to the siliceous ores of the areas named. For German Lorraine the following valuations have been made :—

Kohlmann's Estimates.

	Calcareous.	Siliceous.
	Millions of Tons.	Millions of Tons.
North of Fentsch (Aumetz Arsweiler) . .	863	263
Between Orne and Fentsch	385	
South of Orne	180	150
Totals	1428	413

This gives a rough average of 1840 millions. On the other hand, the Duisburg Chamber of Commerce compiled the following estimate :—

	Millions of Tons.
Calcareous ore	1600
Siliceous ore	1400
Lean ore	250
Total	<u>3250</u>

These figures are, however, exaggerated. Bailly estimated the available ores of the German Lorraine region as 1100 millions. According to Tille the percentage of iron in the German ore has fallen somewhat during recent years, the impoverishments amounting to about 4 per cent. The French ore, when smelted in the blast-furnace, gives a yield of about 6 per cent. higher than that of the German ore; its average iron contents is 3 per cent. higher. On the other hand, other estimates seem to show that the French ores average from about 5 to 8 per cent. higher in iron, and could therefore be advantageously substituted for those of Germany and Luxemburg.

The concessions in German territory are naturally taken up by the large ironmasters; the Wendels cover a quarter of the whole area. The Stumm groups have also acquired important concessions, but more widely scattered than those of the Wendels. A table is given showing the distribution of the region amongst the most important concessionaries, with estimates of the available resources of each concession. The French mining law has rendered it possible for the concessionaries in French Lorraine to acquire ore areas on more advantageous terms,

but a good many of the French beds are also held by German and Belgian companies. Indeed it may be said that the works of south-western Germany and of Luxemburg have predominating interests in French Lorraine.

Details are given as to the cost of mining, and comparative tables have been compiled, showing the wages paid for labour in the different districts. A table is also given showing the production of minette for every year since 1871. The output has steadily increased, and the figures compiled for the first half of 1911 show that the increase is being maintained. According to Kohlmann, the tendency to export minette ores from French Lorraine to Germany will increase steadily owing to the higher quality of the ores in French Lorraine, and in particular of those of the Briey district. Estimates are made of the future production of ore and the future requirements of this region, and comparisons instituted between the ore industry of the minette region and that of Sweden.

Mineral Statistics of Algeria.—Dussert¹ gives the following statistics relating to the iron ore production of Algeria. The amount produced during the year 1910 amounted to 1,104,909 tons, of which 859,535 tons were obtained from open quarries and 245,374 tons from mines. The following table gives the production for each year, commencing with 1905 :—

Year.	Tons.
1905	582,655
1906	770,780
1907	993,022
1908	949,556
1909	924,836
1910	1,104,909

The bulk of the ore is exported to Great Britain and Germany. The following table shows the distribution of the product during the years 1905–1909 inclusive :—

	1905.	1906.	1907.	1908.	1909.
France	53,783	52,887	65,035	22,090	19,568
Germany	210,019	329,035	344,264	276,847	237,920
England	286,702	366,925	430,716	495,218	547,745
Austria . . . . .	...	...	41,467	21,250	23,790
Sweden . . . . .	...	...	...	1,075	...
Italy . . . . .	...	...	824	1,495	30
Belgium	1,836	...	90	100	...
North America . . . . .	...	14,586	54,367	..	47,495

The number of workmen employed at ore mines and quarries in Algeria in 1902 is close on 5000.

¹ *Annales des Mines*, 11th Série, vol. i. pp. 252–254.

Iron Trade Statistics.—The production of pig iron in France¹ during 1911 amounted to 4,426,469 tons, including blast-furnace castings. The following table shows the various descriptions produced in 1911:—

	Tons.
Blast-furnace castings	118,362
Foundry pig iron	718,092
Forge „	586,496
Bessemer „	104,205
Basic	2,777,201
Special (without manganese)	65,277
Spiegeleisen, ferro-manganese, &c.	46,770
Other descriptions	10,066
Total	<u>4,426,469</u>

The production of steel ingots in France² in 1911 amounted to 3,680,613 tons, as against 3,390,309 tons in 1910. The output of ingots during 1911 is tabulated below:—

	Tons.
Acid Bessemer	75,158
Basic Bessemer	2,389,352
Acid open-hearth	1,185,345
Crucible and electric	30,758
Total	<u>3,680,613</u>

The output of semi-manufactured steel during 1911 is summarised in the following table:—

	Tons.
Basic Bessemer	1,398,695
Acid Bessemer	4,252
Acid open-hearth	332,215
Crucible	4,067
Electric furnace	4,919
Total	<u>1,744,148</u>

Of the total, 1,149,176 tons were blooms and 594,972 tons were billets.

The output of finished steel products in 1911 totalled 2,638,484 tons, details of which are as follows:—

	Tons.
Rails	449,818
Tires	40,336
Joists	212,068
Shapes	409,181
Merchant steel	709,131
Rods	123,213
Wire	62,160
Tubes and pipes	45,050
Tinplates	37,471
Sheets and plates	449,234
Forgings	59,038
Castings	41,784
Total	<u>2,638,484</u>

¹ *Comité des Forges de France, Bulletin* No. 3090.

² *Ibid.*, No. 3096.

P. Anglès d'Auriac¹ reviews the conditions of the iron and steel industry in the north of France, and forecasts the direction in which future developments will be made. One-third of the whole production of wrought iron and one-quarter of the whole production of ingot steel in France are made in the northern district, in which 240,000 workmen are employed, while the consumption of raw materials amounts to 750,000 tons of coke, 800,000 tons of coal, and 1½ million tons of ore. The progress of events from the year 1870 to the present time is noted and includes the introduction in the north of France of the Bessemer process, the improved open-hearth process, and the basic process. 411,000 tons of basic steel were produced in 1910, out of a total steel production of 441,000. The production of acid steel is, therefore, only about 3 per cent. of the total.

VIII.—GERMANY.

Mineral Statistics.—The production of coal² in Germany during 1911 amounted to 160,742,272 tons. The quantity of lignite produced totalled 73,516,789 tons, and the make of coke was 25,405,108 tons. The manufacture of briquettes amounted to 21,827,667 tons, of which 4,990,988 tons were coal briquettes and 16,836,679 tons lignite briquettes.

Coal Reserves.—F. Frech,³ who has devoted much time to the study of the world's coal supplies and their possible duration, has recently put forward more detailed statements regarding the coal deposits of Germany. As far as can be gathered from the present somewhat inadequate data, the two most important German coal-fields, those of Upper Silesia and the Westphalian district, each boast a quantity of coal which, in any case, may be estimated to equal the aggregate coal wealth of England. Added to these is the Saarbrücken district, extending towards Pfalz and Lorraine, with 7000 to 8000 million tons of coal, with the narrower Saar district, besides the Lower Silesian and the Saxon coal deposits, which, however, are of smaller importance. Owing to the marked compactness of the German coal-beds and their comparatively limited areas, an increase in production, such as has taken place in Great Britain and the United States, is not possible, and the time when the two principal German coal-fields will be exhausted may therefore be put as more than a thousand years distant.

Iron Trade Statistics.—The output of pig iron⁴ in Germany and Luxemburg during 1911 was the highest on record, amounting to

¹ *Comptes Rendus de la Société de l'Industrie Minière*, 1911, pp. 507-509.

² *Iron and Coal Trades Review*, vol. lxxxiv. p. 212.

³ *Engineering*, vol. xciii. pp. 462-463.

⁴ *Verein deutscher Eisen- und Stahl-Industrieller*, 1911, No. 16; *Iron and Coal Trades Review*, vol. lxxxiv. p. 54.

15,534,223 tons, as against 14,793,325 tons in 1910. The production of the various kinds during 1911 was as follows:—

	Tons.
Foundry	3,063,588
Bessemer	374,455
Basic	9,851,113
Spiegeleisen, ferro-manganese, &c.	1,733,280
Forge	511,792

The total production of steel¹ in Germany during 1911 showed an advance of 1,320,695 tons as compared with the previous year, being 15,019,333 tons as against 13,698,638 tons. The production of the different classes of steel during 1911 was as follows:—

Ingots—	Tons.
Acid Bessemer	187,359
Basic „	8,640,164
Acid open-hearth	281,877
Basic „	5,501,147
Castings—	
Acid	102,018
Basic	167,354
Crucible	78,760
Electric	60,654
Total	<u>15,019,333</u>

The 187,359 tons of acid Bessemer ingots were produced at 3 works, while 24 works contributed to the 8,640,164 tons of basic Bessemer ingots. Acid open-hearth ingots were produced at 15 works, while 67 works produced the basic open-hearth ingots. Acid steel castings were produced at 40 works and basic steel castings at 44 works, 7 of these works producing both varieties. The total number of works producing steel was 120.

German Tinplate Industry.—The Tinplate Sales Association of Cologne, which has recently celebrated the fiftieth year of its existence, has published a memorial, showing the development of the tinplate industry in Germany during that period, an abstract of which has appeared.²

IX.—GREECE.

Mineral Statistics.—The official statistics³ for 1910 show that the total iron ore production in Greece during the year amounted to 608,000 tons, to which the islands contributed the major quantity, Seriphos alone being credited with 174,000 tons, containing 51 per cent. of iron. The output of manganiferous ore was 35,600 tons, and

¹ *Verein deutscher Eisen- und Stahl-Industrieller*, 1912, No. 4; *Iron and Coal Trades Review*, vol. lxxxiv. p. 494.

² *Iron and Coal Trades Review*, vol. lxxxiv. p. 649.

³ *Ibid.*, vol. lxxxiii. p. 885.

the production of iron pyrites was 27,560 tons (containing 44 per cent. of sulphur), while mixed sulphur ores amounted to 51,530 tons. Chrome ores from Thessaly were worked to the extent of 7000 tons.

X.—HOLLAND.

Mineral Statistics.—It is stated¹ that the output of the coal-mines in the Netherlands in 1910 was 1,292,289 tons. Of the six mines which were in operation during that year, five were worked by private enterprise and one by the State. According to a table published by the Government Institute for the Geological Exploration of the Netherlands, the coal reserves of that country, at a workable depth, are estimated at 3,000,000,000 metric tons, and those at a depth of from 1200 to 1500 metres, which are to be regarded as a reserve for the future, are estimated at 1,500,000,000 tons.

XI.—JAPAN.

Mineral Statistics.—In an historical account of the mining industry of Japan, K. Nishio² gives statistics relating to the production of manganese ore, graphite, coal, and petroleum, from which the following figures relating to the output from the years 1892 to 1908 are taken :—

Year.	Manganese Ore, Long Tons.	Graphite, Long Tons.	Coal, Long Tons.	Petroleum, Barrels.
1892	4,913	59	3,129,409	82,833
1893	3,958	27	3,271,244	106,983
1894	13,064	1066	4,214,253	172,711
1895	16,753	428	4,718,914	169,873
1896	17,559	210	4,946,568	236,819
1897	15,097	382	5,131,628	262,571
1898	11,256	339	6,640,463	391,015
1899	11,098	52	6,653,476	539,098
1900	15,498	92	7,362,891	871,740
1901	15,928	86	8,879,511	1,117,995
1902	10,638	95	9,656,295	997,543
1903	5,489	111	10,021,893	1,210,340
1904	4,236	212	10,649,026	1,220,744
1905	13,723	204	11,467,845	1,352,574
1906	12,572	138	12,892,721	1,571,367
1907	20,153	101	13,736,182	1,727,298
1908	10,897	147	14,761,476	1,872,592

¹ *Board of Trade Journal*, vol. lxxvi. p. 641.

² *Bulletin of the American Institute of Mining Engineers*, 1912, p. 143.

XII.—*ROUMANIA.*

Mineral Statistics.—It is stated¹ that a total of 1,404,400 metric tons of petroleum were delivered to Roumanian refineries in 1911, as against 1,215,300 metric tons in 1910. The yield of petroleum in the refineries in 1911 was as follows: Benzine, 260,653 metric tons; burning oil, 312,711 metric tons; mineral oil, 24,703 metric tons; and residue, 783,136 metric tons. Nearly half of the production was used in Roumania.

XIII.—*RUSSIA.*

Mineral Statistics.—The production of iron ore in Russia during 1910 amounted to 5,637,635 tons.² The coal output of Russia in Europe during 1911 was 23,197,000 tons. Of the total, Donetz produced 16,380,000 tons, Poland 5,792,000 tons, Ural 797,000 tons, Moscow 174,000 tons, and Caucasus 54,000 tons. The foregoing figures of the coal production do not, as indicated, include Turkestan and Siberia. The production from those districts is something over one million tons per annum, the figure for 1910 being 1,244,000 tons.

Iron Trade Statistics.—B. Simmersbach,³ in an article describing the rise and progress of the Russian iron industry, gives the following statistics of the manufacture of pig iron and steel:—

Pig Iron

Year.	Tons.	Year.	Tons.
1890	888,000	1905	2,660,000
1895	1,402,000	1906	2,619,000
1900	2,848,000	1907	2,723,000
1901	2,783,000	1908	2,749,000
1902	2,521,000	1909	2,817,000
1903	2,405,000	1910	3,040,000
1904	2,930,000		

In 1910 there were produced 2,846,000 tons of open-hearth steel, 405,180 tons of Bessemer steel, and about 97,000 tons of wrought iron. The finished products amounted to 2,977,800 tons, including 190,770 tons of girders and sleepers, and 480,000 tons of rails.

The output of pig iron in Russia during 1911⁴ amounted to 3,521,000 tons as against 2,983,000 tons in 1910. With the exception of the North, where only a negligible quantity of pig iron is

¹ *Nachrichten für Handel und Industrie* (Berlin), March 15, 1911, *Board of Trade Journal*, vol. lxxvii. p. 35.

² *Iron and Coal Trades Review*, vol. lxxxiv. p. 1031, vol. lxxxv. p. 93.

³ *Oesterreichische Zeitschrift*, vol. lxx. pp. 701-704, 721-723.

⁴ *Iron and Coal Trades Review*, vol. lxxxiv. p. 877.

smelted, each district participated in the increase of production. The following table shows the production in 1911 by districts:—

	Tons.
South Russia	2,375,000
Ural	721,000
Moscow	84,000
North	1,000
Poland	340,000
Total	<u>3,521,000</u>

The output of steel of each of the districts during 1911 was as follows:—

	Tons.
South Russia	2,096,000
Ural	771,000
Moscow	179,000
Volga	163,000
North and Baltic	217,000
Poland	448,000
Total	<u>3,874,000</u>

Of the total steel produced in 1911 about five-sixths was open-hearth steel. The total output of finished iron and steel in 1911 amounted to 3,258,000 tons, and comprised the following:—

	Tons.
Joists and channels	266,000
Merchant bars	1,179,000
Rails	497,000
Wire	241,000
Roofing sheets	333,000
Plates and sheets	369,000
Unenumerated	373,000
Total	<u>3,258,000</u>

Iron Trade Statistics of South Russia.—Complete figures relating to the production of iron and steel in South Russia during the year 1911 are available.¹ The pig iron production was as follows:—

	1911. Tons.
Foundry pig	519,000
Basic and Bessemer	1,788,000
Other descriptions	69,000
Total	<u>2,376,000</u>

The production of steel ingots in 1911 was as follows:—

	1911. Tons.
Open-hearth	1,473,000
Bessemer (acid)	469,000
Bessemer (basic)	154,000
Total	<u>2,096,000</u>

¹ *Iron and Coal Trades Review*, vol. lxxxiv. p. 767.

XIV.—*SPAIN*.

Mineral Statistics.—The output¹ of bituminous coal in Spain during 1910 amounted to 3,600,056 tons, as against 3,662,573 tons in 1909; the anthracite output totalled 211,958 tons, and there were produced also 245,518 tons of lignite. The production of iron ore in 1910 was 8,650,000 tons, being slightly in excess of the production in 1909.

The total make of coke in Spain during 1910 was 521,078 tons,² comprising the following amounts from the different provinces: Vizcaya, 261,967 tons; Oviedo, 155,655 tons; Santander, 41,772 tons; Cordova, 39,037 tons; and Leon, 22,647 tons. The production of briquettes in the different provinces was as follows: Oviedo, 139,000 tons; Leon, 98,787 tons; Valencia, 85,284 tons; Seville, 77,163 tons; Cordova, 57,225 tons; Saragossa (lignite briquettes), 17,432 tons—total, 474,891 tons.

Iron Trade Statistics.—The pig iron production³ of Spain in 1910 amounted to 373,000 tons, or less than in any year since 1902. The production of rolled iron, wrought iron, and forgings in 1910 was 58,100 tons; that of rolled steel was 171,600 tons; and that of steel forgings and castings 11,200 tons. Other manufactures of iron and steel to the amount of 16,400 tons were made.

XV.—*SWEDEN*.

Mineral and Iron Trade Statistics.—Particulars are given⁴ of the quantity of ore and refractory material mined in Sweden in 1910 and in the preceding decade. The production of pig iron, steel, and finished iron and steel goods in 1910 is also given.

According to the returns just published by the Swedish Ironmasters' Association,⁵ the production of pig iron in Sweden in 1911 was the largest on record for the country, being 633,800 tons, or 29,500 tons more than in 1910. The output of puddled iron amounted to 146,700 tons in 1911. The production of steel ingots in 1911 was 461,000 tons, of which 93,800 tons were Bessemer and 367,200 tons open-hearth.

¹ *Iron and Coal Trades Review*, vol. lxxxiv. p. 916.

² *Ibid.*, p. 957.

³ *Ibid.*, p. 916.

⁴ *Gluckauf*, vol. xlvii. pp. 1847-1851.

⁵ *Bihang till Jernkontorets Annaler*, 1912, p. 135. *Iron and Coal Trades Review*, vol. lxxxiv. p. 205.

XVI.—UNITED STATES.

Mineral Statistics.—The total output of coal in the United States during 1911 is estimated at 483,192,888 short tons, of which 86,896,065 tons were anthracite and 396,296,823 tons bituminous. The output of iron ore amounted to 41,815,471 tons, and the production of petroleum was 209,931,884 barrels. There were also produced 1125 tons of tungsten ore.¹

According to E. W. Parker² the production of coke in the United States in 1910 amounted to 41,708,810 short tons, in the manufacture of which 63,088,327 tons of coal were used. There were 578 coking establishments in existence at the end of 1910, representing 104,440 ovens. Nine establishments, representing 894 ovens, were abandoned or dismantled, and 100 establishments were idle during 1910. There were also 4078 by-product coke-ovens completed and 1200 building in 1910. The production amounted to 7,138,734 short tons. Of the completed ovens, 1387 were of the Semet-Solvay type, 2104 United Otto, 307 Rothberg, and 300 Didier ovens; of those building, 900 were Koppers and 300 Didier ovens. A table showing the total quantity and value of the coke, gas, tar, ammonia, &c., produced at the by-product ovens during the years 1908, 1909, and 1910 is given.

Petroleum.—According to D. T. Day³ the production of petroleum in the United States in 1910 amounted to 209,556,048 barrels, as compared with 183,170,874 barrels in 1909. Of the total California produced 73,010,560 barrels, Oklahoma 52,028,718 barrels, and Illinois 33,143,362 barrels. During the year the consumption of fuel oil by the railroads of the United States was 24,586,108 barrels, as compared with 19,939,394 barrels in 1909, being an increase of 4,646,714 barrels.

Graphite.—According to the United States Geological Survey,⁴ the production of natural graphite in the United States in 1910 was 35,945 net tons of amorphous graphite, mainly used for fertiliser filler, and 5,590,592 lbs. (2795 net tons) of crystalline. The production of artificial graphite at Niagara Falls, which had averaged 6,000,000 lbs. (3000 net tons) for a number of years, increased to 13,149,100 lbs. (6574 net tons) in 1910.

Iron Trade Statistics.—According to statistics collected by the American Iron and Steel Association,⁵ the total production of all kinds of pig iron in the United States in 1911 was 23,649,344 tons,

¹ *Engineering and Mining Journal*, vol. xciii. p. 1.

² *United States Geological Survey (Mineral Resources)*, 1910.

³ *Petroleum Review*, vol. xxv. pp. 435-436.

⁴ *Iron Age*, vol. lxxxviii. p. 477.

⁵ *Bulletin of the American Iron and Steel Association*, vol. xlvi. pp. 12-13.

against 27,303,567 tons in 1910. The total in 1911 comprised the following: Bessemer and low-phosphorus, 9,409,107 tons; basic, 8,520,029 tons; charcoal, 278,676 tons; spiegeleisen and ferromanganese, 184,717 tons. The number of furnaces in blast on December 31, 1911, was 231, and the number idle, including furnaces being rebuilt, was 235.

According to the American Iron and Steel Association¹ the production of all kinds of steel ingots and castings in the United States in 1911 amounted to 23,675,501 tons, as against 26,094,919 tons in 1910. Of the total production in 1911, 23,029,479 tons were ingots and 646,022 tons were castings. The following table gives the production of ingots and castings by processes:—

	Tons.
Acid open-hearth	912,718
Basic „	14,685,932
Acid Bessemer.	7,947,849
Crucible	97,653
Electric and miscellaneous	31,349
Total	<u>23,675,501</u>

Of the total production of Bessemer steel in 1911, 7,893,961 tons were made by the standard Bessemer process, 26,219 tons by the Tropenas process, and 27,669 tons by other modifications of the Bessemer process.

The production of steel by the electric process in 1911 amounted to 29,105 tons, of which about 27,227 tons were ingots and about 1878 tons were castings.

The production of steel in 1911 by various minor processes amounted to 2244 tons.

According to statistics collected by the American Iron and Steel Association² the production of all kinds of rails in the United States in 1911 amounted to 2,822,790 tons, as against 3,636,031 tons in 1910. Included in the total for 1911 are 205,409 tons of girder and T-steel rails for electric and street railways. Of the total in 1911, 1,138,633 tons were Bessemer, 1,676,923 open-hearth, and 7234 tons miscellaneous.

Census of United States Iron Industry.—E. D. Durand³ has issued statistics of the iron and steel industries of the United States for 1909. There were 208 establishments engaged in the manufacture of pig iron in 1909, a decrease of 16 from the number in 1899, but an increase of 17 over that of 1904. The employees, including salaried officials, clerks, and wage-earners, in 1909 numbered 43,013; in 1904, 37,414; and in 1899, 41,121, an increase of 15 per cent. for 1904–1909, and a decrease of 9 per cent. for 1899–1904.

There were 388 completed furnaces with a daily capacity of 101,267

¹ *Bulletin of the American Iron and Steel Association*, vol. xlv. p. 44.

² *Ibid.*, p. 37.

³ *Preliminary Census Returns; Iron Age*, vol. lxxxviii. pp. 470–471.

tons in 1909, compared with 343 completed furnaces with a capacity of 78,180 tons in 1904, and 343 with a capacity of 54,425 tons in 1899, an increase for the decade of 13 per cent. in number and 86 per cent. in capacity.

There were 446 establishments in 1909 equipped for the manufacture of steel or for the hot rolling of iron or steel, compared with 415 establishments in 1904 and 445 in 1899. The employees, including salaried officials, clerks, and wage-earners, in 1909 numbered 260,123; in 1904, 221,892; and in 1899, 190,703; an increase of 17·2 per cent. for 1904-1909, and of 16·4 per cent. for 1899-1904.

The daily capacity of rolled iron and steel on double turn of the rolling-mill establishments was 150,000 tons in 1909, 106,000 tons in 1904, and 87,000 tons in 1899, an increase for the decade of 73 per cent.

The wire industry in 1909 employed 19,931 persons, including salaried officials, clerks, and wage-earners; in 1904, 5318; and in 1899, 1697; an increase of 274·8 per cent. for 1904-1909, and of 213·4 per cent. for 1899-1904. There were 42,799 wire-drawing blocks, of which 21,081 were reported in kind (rod, 4265; redrawing, 7043; and fine wire, 9773), and 21,718 with kind not reported, with a total annual capacity of 3,146,000 tons; 4428 wire-nail machines with an annual capacity of 18,757,000 kegs. and 446 woven-wire fence machines with an annual capacity of 481,000 tons of fencing.

There were 31 establishments reporting the dipping of tin and terne plates in 1909, compared with 36 in 1904 and 57 in 1899; of these, 5 in 1909, 9 in 1904, and 22 in 1899 purchased their black plates, the balance rolling them. The employees, including salaried officials, clerks, and wage-earners, in 1909 numbered 5845; in 1904, 5131; and in 1899, 4004; an increase of 13·9 per cent. for 1904-1909, and of 28·1 per cent. for 1899-1904.

XVII.—COMPARATIVE TABLES.

The World's Production of Coal, Iron, and Steel.—For purposes of comparison the following summary of the production of coal in the principal countries of the world is appended:—

Country.	Year.	Production in Tons.
United Kingdom	1911	271,878,924
Australasia—		
New South Wales	1911	8,691,604
Queensland	1910	871,166
Tasmania	1909	66,162
Victoria	1910	369,059
Western Australia	1910	262,166
Austria-Hungary, coal	1911	14,861,314
" lignite	1911	25,255,429
Belgium	1911	23,125,140
Canada (short tons)	1911	11,291,553
Chile	1909	898,971
China	1909	12,840,000
France	1911	38,643,561
Germany and Luxemburg, coal	1911	160,742,272
" lignite	1911	73,516,789
Holland	1910	1,292,289
India	1910	12,047,413
Italy	1910	562,153
Japan	1910	15,535,285
Natal	1910	2,296,646
Rhodesia, Southern	1910	180,068
Russia	1911	23,197,000
Spain	1910	3,600,056
Sweden	1910	302,786
Transvaal Colony	1909	3,312,413
United States	1911	483,192,888

A similar summary showing the production of pig iron is as follows:—

Country.	Year.	Production in Tons.
United Kingdom	1911	9,718,638
Australasia, New South Wales	1911	24,658
Austria-Hungary	1910	1,967,000
Belgium	1911	2,106,120
Canada	1911	917,535
China	1910	130,000
France	1911	4,426,469
Germany and Luxemburg	1911	15,534,223
India	1909	39,350
Italy	1910	353,239
Japan	1910	58,205
Mexico	1909	58,850
Russia	1911	3,521,000
Spain	1910	373,000
Sweden	1911	633,800
United States	1911	23,649,344

World's Production of Steel (in tons).

	Year.	Bessemer.		Open-hearth.		Crucible.	Electric.	Castings.	Total.
		Acid.	Basic.	Acid.	Basic.				
United Kingdom .	1911	887,767	573,373	3,131,118	1,869,354	...	...	...	6,461,612
Austria-Hungary .	1911	34,358	293,700	1,979,902		17,467	22,867	Included in Bessemer and open-hearth	2,348,294
Belgium .	1911	1,755,500		130,660		...	...	52,640	1,944,820
Canada .	1911	209,817	...	...	651,676	740	740	13,982	876,215
France .	1911	75,158	2,389,352	1,185,345	...	30,758	30,758	...	3,080,613
Germany .	1911	187,359	8,640,164	281,877	5,501,147	...	...	408,786	15,019,333
Italy .	1910	...	...	732,000 (not classified)	...	...	...	...	732,000
Russia .	1911	...	...	3,874,000	...	...	...	...	3,874,000
Spain .	1909	113,250		131,750		...	...	...	245,000
Sweden .	1911	93,800		367,200		...	...	...	461,000
United States .	1911	7,947,849	...	912,718	14,685,932	97,653	29,105	Included in Bessemer and open-hearth	23,675,501

The World's Supply of Iron Ore.—P. Anglès d'Auriac¹ discusses the evolution of metallurgical processes in their relation to the world's supply of iron ores. It is in the manufacture of open-hearth steel that the greatest progress has been made. Three countries together furnish more than four-fifths of the total steel production of the world, namely, the United States, Germany, and Great Britain. Diagrams and curves are given showing the progress in each country. The Bessemer process requires pig iron of a definite chemical composition which may not vary within certain relatively circumscribed limits; while the open-hearth furnace, on the other hand, can be adapted to suit pig irons of widely varying composition, and the ease with which various grades of steel can be made in the open-hearth furnace confers upon that process a degree of elasticity which the Bessemer process lacks. On the other hand, the open-hearth process is at a disadvantage with the Bessemer process owing to the fact that the working of a charge takes longer and that the costs are higher. In America the open-hearth process is daily gaining ground. In 1910 it represented 63·7 per cent. of the total production, 59 per cent. being basic open-hearth steel and 4·7 acid open-hearth steel. The special conditions which have led to these circumstances in the United States are discussed. In Germany conditions are quite different. Four-fifths of the iron ores treated within the Zollverein are obtained from Alsace-Lorraine and from Luxemburg, or, in other words, from the minette district where the ores are exclusively of a type which only lends itself to treatment by the basic process. On the other hand, the production of iron ore in Germany is far short of the consumption, and a large proportion is therefore derived from other countries, of which Sweden is the principal and Spain the next. In 1910 the imports of Swedish ore into Germany amounted to 3,249,000 tons, while the Spanish imports were 2,861,000. The production from French Lorraine is rapidly growing, and now amounts to 18 per cent. of the total import, 1,774,000 tons having been imported in 1910. The French imports are mostly derived from the Briey field, and are similarly of the minette type. Indeed, the minette deposits of French and German Lorraine constitute the largest ore reserve in the world, and furnish a guarantee of the continued adoption and success of the basic process in France, Germany, and Luxemburg. In Great Britain conditions differ once again, being controlled by two factors, the preference which is evinced in that country for acid processes, and the insufficiency of the native ore supply, which necessitates the importation of foreign ores of a relatively pure description. In 1909 the consumption of iron ore in Great Britain was 21,642,000 tons, whereas the whole production was only 15,220,000. The difference, 6,422,000, was derived from Spain (which furnished three-fourths of the imports, or 4,802,000 tons), Algeria (which furnished 489,000 tons), and Sweden (from which 295,000 tons were obtained). Of the ores derived from these countries it is mainly the pure magnetites which are sent to

¹ *Bulletin de la Société de l'Industrie Minérale*, vol. xv. pp. 441-474.

England, while the phosphoric qualities are imported into Germany. As the supply of ore suitable for acid processes is not only distinctly limited, but is gradually approaching exhaustion, the tendency in Great Britain will obviously be in the direction of a further adoption of the basic process, and already imports of ore have been made from Briey into the Cleveland district. It may be foreseen, therefore, that while the open-hearth process will maintain its proportional preponderance, the amount of acid steel made by this process will diminish gradually, while the proportion of basic open-hearth steel would increase. During the years 1900-1910 the percentage of basic open-hearth steel increased from 6 per cent. to 26.3 per cent., while the amount of acid steel fell from 58.4 to 44.1 per cent., although the total percentage of open-hearth steel increased from 64.4 to 70.4 per cent. On the other hand, the percentage of Bessemer steel fell from 25.6 per cent. to 18.9 per cent. Summarising the statistical information available, it will be seen that whereas in the year 1900 the United States, Germany, and Great Britain produced 21,732,000 tons of ingot steel, of which 12,210,000 tons were acid steel and 9,522,000 were basic steel (56.2 per cent. acid and 43.8 per cent. basic), these three countries in 1910 produced no less than 45,755,000 tons, of which 14,958,000 tons were acid steel and 30,797,000 were basic steel (32 per cent. acid, 67 per cent. basic). During 1900-1910 the percentage of acid Bessemer steel fell from 38.2 per cent. to 23.8 per cent., and that of basic steel from 21.3 per cent. to 1.9 per cent., while the production of open-hearth steel rose from 40.5 per cent. to 57.2 per cent. At the present moment the production of basic open-hearth steel alone amounts to 48.3 per cent. of the total production. The victory of the open-hearth furnace over the converter and the noteworthy predominance of the basic processes over the acid processes are thus clearly brought out by the experience of the last ten years. The question arises, to what extent this tendency will go? The answer is complicated by the intervention of electrical processes, for it is indubitable that the employment of electric furnaces in connection with Bessemer converters in America will considerably extend the scope of the Bessemer process by solving the difficulties which arise owing to the occurrence of phosphorus in Lake Superior ores. On the other hand, in the Old World it may be foreseen that the electric furnace will act as an adjunct for the finishing of basic steel, and will serve in lieu of steel now produced in the open-hearth furnace. Although the production of electric steel is rapidly increasing, it is still not a factor of importance. In 1910 the United States produced 53,000 tons, as against 14,000 in 1909; while the production in Germany was 36,000, as against 18,000 in the previous year. It is, however, not to be supposed that the possibilities of the electric furnace have been exhausted. In conclusion, the forecast is made that, except for the eventual support lent by the electric furnace to converter methods, the basic open-hearth process will steadily increase in favour.

World's Production of Tungsten.—H. Leiser¹ gives the following table showing the world's production of tungsten in 1910 :—

	Tons.
North America	1200 (concentrates)
Australia	1200
Australia	120 (scheelite)
India and Japan	120 (concentrates)
South America	1080
Spain	240
Portugal	1200
Germany	35
Austria	45
Great Britain	480
Other countries	180
	<u>5900</u>

¹ *Chemiker Zeitung*, vol. xxxv. pp. 665–666.

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